SELECTION OF A DEVICE LEVEL FIELDBUS

FOR THE

PAPER CONVERTING INDUSTRY

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A thesis submitted in candidature for the degree of Master of Philosophy
to the University of Wales.

June 2002

SELECTION OF A DEVICE LEVEL FIELDBUS FOR THE PAPER CONVERTING INDUSTRY

DECLARATIONS

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ACKNOWLEDGEMENTS

I would like to express my gratitude to my supervisors Dr Eifion Breeze and Dr Hefin Rowlands for their supervision and encouragement throughout the research.

I would also like to thank my father in helping me overcome my atrocious grammar and spelling.

Gratitude also goes to all the numerous people who have kindly helped with the research, especially Georgia Pacific for their sponsorship.

Furthermore I would like to thank my wife and two sons for their constant love, humour and support during the last two years.

SELECTION OF A DEVICE LEVEL FIELDBUS FOR THE PAPER CONVERTING INDUSTRY

ABSTRACT

Fieldbus concepts were initially developed in the mid-1980's with wider acceptance starting in the 1990's - prompted by the advances in technology and ever increasing numbers and diversity of industrial specific products being introduced. This growing trend towards open fieldbuses and its associated potential benefits has prompted over 80% of industrial plants to evaluate these more advanced networks.

With 200 or so different fieldbus systems on the market, this thesis focuses on the selection of an **optimum fieldbus** for machine control within the paper converting industry, in particular Georgia Pacific's plant in South Wales. In addition to this, the benefits of the optimum fieldbus are considered against the existing proprietary network and a recommendation given.

In order to provide a means of identifying the optimum fieldbus several tools and techniques have been used - elimination by evaluation, potential risk analysis, direct comparison cost analysis and finally a field trial.

The findings from this research demonstrates that fieldbus is a practical and effective technology for delivering real benefits to the end user as well as being economically viable when correctly selected for a particular application

The results of this research leads the author to comprehensively recommend that Georgia Pacific adopt DeviceNet as the standard network for machine control within their paper converting process.

SELECTION OF A DEVICE LEVEL FIELDBUS FOR THE PAPER CONVERTING INDUSTRY

TABLE OF CONTENTS

Page No

CHAPTER 1 1
Introduction

1.1 Tools and Techniques 6
1.2 Aims and Objectives 7
1.3 Outline of Study 8

CHAPTER 2 10
Development and Future of Fieldbus

2.1 Traditional Machine Control 10
2.2 Programmable Controllers 11
2.3 Communications 13
2.4 Fieldbuses 15
2.4.1 Control Network Hierarchy 18
2.5 Future 21
2.6 Summary 27

CHAPTER 3 30
Fundamentals of Fieldbus Systems

3.1 Overview 30
3.2 Communication Protocol 32
3.2.1 ISO/OSI Reference Model 32
3.2.2 Physical Layer 35
3.2.3 Data Link Layer 35
3.2.4 Application Layer 36
3.3 Data Communications 36
3.3.1 Serial Communications 36

SELECTION OF A DEVICE LEVEL FIELDBUS FOR THE PAPER CONVERTING INDUSTRY

TABLE OF CONTENTS

Page No

3.3.2 Data Synchronization ... 38
3.3.3 Transmission Speeds ... 38
3.3.4 Data Transmission Techniques ... 39
3.3.4.1 Baseband Transmission ... 40
3.3.4.2 Broadband Transmission ... 40
3.4 Interfacing ... 41
3.4.1 EIA RS-485 ... 41
3.5 Topology ... 42
3.6 Medium Access Control Methods ... 48
3.6.1 Single Master (Poll/Select) ... 49
3.6.2 CSMA/CD ... 49
3.6.3 CSMA/BA ... 50
3.6.4 Token Passing ... 50
3.6.4.1 Token Ring ... 51
3.6.4.2 Token Bus ... 51
3.7 Error Detecting and Checking Mechanisms ... 51
3.7.1 Cyclic Redundancy Check (CRC) ... 51
3.7.2 Complementary Data Retransmission (CDR) ... 52
3.7.3 Hamming Distance (HD) ... 52
3.7.4 Data Echo Feature ... 53
3.8 Node Addressing ... 53
3.8.1 Master/Slave (One to One) ... 53
3.8.2 Peer to Peer (Slave to Slave) ... 54
3.8.3 Publisher-Subscriber (Producer/Consumer) ... 55
3.9 International Fieldbus Standards ... 55
3.9.1 International Electrotechnical Commission (IEC) ... 57
3.9.2 International Standards Organization (ISO) ... 58

SELECTION OF A DEVICE LEVEL FIELDBUS FOR THE PAPER CONVERTING INDUSTRY

TABLE OF CONTENTS

Page No

3.9.3 CENELEC 59
3.10 Summary 60

CHAPTER 4 63
Fieldbus Selection

4.1 Principles of Decision Analysis 64
4.2 Techniques of Decision Analysis 65
4.3 The Decision Statement 69
4.4 Must Objectives 69
4.5 Want Objectives 70
4.5.1 Technical Characteristics/Performance Criteria 71
4.5.2 Strategic Criteria 72
4.5.3 Weighting of Objectives 72
4.6 Evaluating Chosen Alternatives against Criteria 76
4.6.1 Evaluation of Alternatives against Must Criteria 77
4.6.1.1 Bus Length 77
4.6.1.2 Node Capacity 79
4.6.1.3 Discrete I/O Capacity 79
4.6.2 Evaluation of Alternatives Against Technical/Performance Criteria 81
4.6.2.1 Topologies 81
4.6.2.2 Physical Bus Media 82
4.6.2.3 Capabilities to Supply Power 85
4.6.2.4 Maximum Number of Addressable/Attachable Nodes 86
4.6.2.5 Bus Length 87
4.6.2.6 Modes of Operation 88
4.6.2.7 Data Transfer Size per Message Segment 90

SELECTION OF A DEVICE LEVEL FIELDBUS FOR THE PAPER CONVERTING INDUSTRY

TABLE OF CONTENTS

Page No

4.6.2.8 Determinism ... 91
4.6.2.9 Detecting Transmission Errors and Error Correction ... 93
4.6.2.10 Performance ... 95
4.6.2.11 Composite Scoring ... 96
4.6.3 Evaluating Alternatives Against the Strategic Criteria ... 97
4.6.3.1 Diagnostic/Predictive Features ... 100
4.6.3.2 Open System with Multi Vendor Support ... 100
4.6.3.3 Number of Vendors Offering Products for Fieldbus ... 102
4.6.3.4 Industrial Related Products Compatible with Fieldbus ... 103
4.6.3.5 Interchangeable/Interoperable Products ... 104
4.6.3.6 Ease of Use ... 104
4.6.3.7 Cost Per Node ... 105
4.6.3.8 Installation and Commissioning Costs ... 105
4.6.3.9 Maintenance Costs ... 106
4.6.3.10 Overall Cost ... 107
4.6.3.11 Technical/Development Support ... 107
4.6.4 Overall Ratings of the Alternatives ... 108
4.7 Potential Risks ... 111
4.8 Cost Analysis ... 115
4.8.1 Cost Comparison Software ... 115
4.9 Summary ... 128

SELECTION OF A DEVICE LEVEL FIELDBUS FOR THE PAPER CONVERTING INDUSTRY

TABLE OF CONTENTS

Page No

CHAPTER 5 130
Fieldbus Evaluation Trial

5.1 Method 130
5.1.1 Constructing the Starter Kit 133
5.2 Field Trial 153
5.2.1 Cable Planning 153
5.2.2 Constructing a PLC Program 158
5.2.3 Installation 158
5.3 Monitoring/Results 158
5.3.1 Monitoring the Construction of the Starter Kit 159
5.3.2 Installation and Commissioning 161
5.3.3 Reliability of Network and Devices 162
5.3.4 Accuracy of Data 162
5.3.5 Ease of Use 162
5.4 Conclusion 163

CHAPTER 6 165
Conclusions and Recommendations

6.1 Recommendations 169
6.2 Further Work 170

References 171

Appendix A Kepner Tregoe Manual A-1

A.1 Kepner Tregoe Training Manual A-1

SELECTION OF A DEVICE LEVEL FIELDBUS FOR THE PAPER CONVERTING INDUSTRY

TABLE OF CONTENTS

Page No

Appendix B Selection Data and Cost Analysis B-1

B.1 Characteristics of Existing Proprietary Network B-2
B.2 DeviceNet Cost Comparison Instruction Manual B-4
B.3 Line 10 Saw I/O Listings B-16
B.4 Saw Cost Analysis Excluding Premium B-21
B.5 Saw Cost Analysis Inclusive of Premium B-26
B.6 Line 10 External Unwind I/O Listings B-31
B.7 Unwind Cost Analysis Excluding Premium B-38
B.8 Unwind Cost Analysis Inclusive of Premium B-43

Appendix C Field Trial C-1

C.1 Line 10 Rewinder Layout Drawing C-2
C.2 Remote I/O Overview of Line 10 .... C-4

SELECTION OF A DEVICE LEVEL FIELDBUS FOR THE PAPER CONVERTING INDUSTRY

LIST OF FIGURES

Page No

Figure 1-1 *Total Worldwide Sales of Field Networks* 4

Figure 2-1 *Traditional Control System* 11
Figure 2-2 *Basic Structure of a PLC* 13
Figure 2-3 *Evolution of Technology in Control Theory* 14
Figure 2-4 *Typical Control System Using Parallel Wire* 15
Figure 2-5 *Typical Fieldbus Cabling* 16
Figure 2-6 *The Control Network Hierarchy* 18
Figure 2-7 *Network Classifications* 19
Figure 2-8 *Smart Appliance* 23
Figure 2-9 *Ideal Architecture for Complex Adaptive Control* 24
Figure 2-10 *Comparison between Conventional and Self Organizing Complex Adaptive System* 25
Figure 2-11 *Predictive Market Growth by Bus Type* 26
Figure 2-12 *Adoption Rate of Countries to Open Digital Communications* 28
Figure 2-13 *Control Networks for the Next Decade* 29

Figure 3-1 *Simple Fieldbus System* 31
Figure 3-2 *The OSI Model* 33
Figure 3-3 *Serial Communications* 37
Figure 3-4 *Parallel Communications* 37
Figure 3-5 *Star Topology* 43
Figure 3-6 *Ring Topology* 45
Figure 3-7 *Bus Topology* 47
Figure 3-8 *Tree Topology* 47
Figure 3-9 *Repeater* 48
Figure 3-10 *Frame Format* 53

SELECTION OF A DEVICE LEVEL FIELDBUS FOR THE PAPER CONVERTING INDUSTRY

LIST OF FIGURES

Page No

Figure 3-11 *Master/Slave Transmission* 54
Figure 3-12 *Peer to Peer Transmission* 54
Figure 3-13 *Publisher Subscriber Method of Operation* 55

Figure 4-1 *Professor Gruhler's General Procedure for Selecting a Network or Bus System* 63
Figure 4-2 *End Users Applications* 98
Figure 4-3 *Machine OEM's Applications* 99
Figure 4-4 *Ethernet and DeviceNet comparison* 114
Figure 4-5 *Initial Screen* 116
Figure 4-6 *1771/1746 Direct Model* 116
Figure 4-7 *Flex I/O Model* 117
Figure 4-8 *DeviceNet Model* 117
Figure 4-9 *Ratio of Distance to Cost* 126
Figure 4-10 *Ratio of Premium per Device to Cost* 127

Figure 5-1 *Line 10 Unwind Stands and Rewinder Section* 131
Figure 5-2 *Line 10 Rewinder* 131
Figure 5-3 *Line 10 Saw* 131
Figure 5-4 *Line 10 Main Control Cabinet* 132
Figure 5-5 *Line 10 Control Cabinet* 132
Figure 5-6 *Contents of DeviceNet Starter Kit* 134
Figure 5-7 *KwikLink Tap (IDC) Micro Quick Disconnect* 135
Figure 5-8 *Assembled KwikLink Media System* 135
Figure 5-9 *ArmorBlock MaXum* 136
Figure 5-10 *Scanner to PC Via Interface* 137
Figure 5-11 *RSLinx Initial Screen* 138

SELECTION OF A DEVICE LEVEL FIELDBUS FOR THE PAPER CONVERTING INDUSTRY

LIST OF FIGURES

Page No

Figure 5-12 *RSLinx Driver Running Screen* 139
Figure 5-13 *RSLinx Network Running Screen* 139
Figure 5-14 *RSLinx Network Browsing Screen* 140
Figure 5-15 *RSNetWorx Browser Screen* 141
Figure 5-16 *DeviceNet Compact Block I/O* 142
Figure 5-17 *Hardware Selection/Network Screen* 142
Figure 5-18 *Node Commissioning Window* 144
Figure 5-19 *Completed Commissioning of Nodes* 145
Figure 5-20 *1771 Scanner Properties Screen* 147
Figure 5-21 *RSNetWorx Scanlist Window* 147
Figure 5-22 *Compiled Scanlist* 148
Figure 5-23 *Automapped Inputs* 149
Figure 5-24 *Edit I/O Parameter Screen* 150
Figure 5-25 *Ladder Logic Program* 151
Figure 5-26 *Ladder Logic Data Monitoring Screen* 152
Figure 5-27 *DeviceNet Cable System* 153
Figure 5-28 *Ratio of Current to Trunk Line Distance* 154
Figure 5-29 *Line 10 DeviceNet Cable Layout* 156
Figure 5-30 *DeviceNet Assistant Network Layout* 157

SELECTION OF A DEVICE LEVEL FIELDBUS FOR THE PAPER CONVERTING INDUSTRY

LIST OF TABLES

Page No

Table 2-1 *History of the Programmable Logic Controller* 12

Table 3-1 *Major Stages in the Development of an International Fieldbus 1984-2000* 56

Table 4-1 *Alternatives Evaluated against MUST Objectives* 67
Table 4-2 *Alternatives Evaluated against WANT Objectives* 67
Table 4-3 *Alternatives and their Total Weighted Scores* 68
Table 4-4 *Weighting of WANT Objectives* 75
Table 4-5 *Maximum Allowable Bus Lengths* 78
Table 4-6 *Maximum Addressable and Attachable Nodes* 79
Table 4-7 *Maximum Theoretical Number of Discrete I/O Points* 80
Table 4-8 *Topology Capabilities of Fieldbuses under Evaluation* 81
Table 4-9 *Evaluation of Physical Media* 83
Table 4-10 *Ability of Fieldbus to Supply Power* 86
Table 4-11 *Maximum Attachable/Addressable Nodes* 87
Table 4-12 *Maximum Allowable Bus Lengths* 88
Table 4-13 *Configurable Operating Modes* 89
Table 4-14 *Configurable Transmission Mode* 90
Table 4-15 *Maximum Data Transfer Size* 91
Table 4-16 *Degree of Determinism* 93
Table 4-17 *Error Checking and Correcting Methods* 95
Table 4-18 *Performance of Fieldbuses* 96
Table 4-19 *Overall Score for Technical/Performance of Chosen Fieldbuses* 97
Table 4-20 *Diagnostic/Predictive Features* 100
Table 4-21 *Number of Vendors offering Products* 103

SELECTION OF A DEVICE LEVEL FIELDBUS FOR THE PAPER CONVERTING INDUSTRY

LIST OF TABLES

Page No

Table 4-22 *Relative Scoring of Availability of Compatible Products for Fieldbuses* ... 103

Table 4-23 *Relative Scores for Interchangeability of Products per Fieldbus Type* ... 104

Table 4-24 *Ease of Use* ... 104

Table 4-25 *Low Cost per Node* ... 105

Table 4-26 *Installation and Commissioning Costs* ... 106

Table 4-27 *Maintenance Costs* ... 106

Table 4-28 *Low Overall Costs* ... 107

Table 4-29 *Technical/Development Support* ... 108

Table 4-30 *Overall Ratings of Selected Fieldbuses* ... 109

Table 4-31 *Model Assumptions* ... 118

Table 4-32 *Device Wire Equivalent and Device Incremental Cost* ... 119

Table 4-33 *Installed Cost Comparison Excluding Premium* ... 122

Table 4-34 *Installed Cost Inclusive of Premium* ... 123

Table 4-35 *Installed Cost Comparison Excluding Premium* ... 124

Table 4-36 *Installed Cost Comparison Inclusive of Premium* ... 125

Table 5-1 *DeviceNet Node Address Settings* ... 142

Table 5-2 *Maximum Trunk Line Distances* ... 154

Table 5-3 *Relationship of Data to Cumulative Drop Line Length* ... 155

Table 5-4 *Relationship between Drop Line Length and Allowable Current* ... 155

SELECTION OF A DEVICE LEVEL FIELDBUS FOR THE PAPER CONVERTING INDUSTRY

NOMENCLATURE

ACK	Acknowledge
ANS	American National Standard
ANSI	American National Standards Institute
ARC	Advisory Research Group
ASCII	American Standard Code of Information Interchange
AS-I	Actuator Sensor-Interface
ASIC	Application Specific Integrated Circuits
BCD	Binary Coded Decimal
BS	British Standard
CAN	Controller Area Network
CAS	Complex Adaptive System
CCITT	Consultative Committee in International Telegraphy and Telephony
CD	Computer Disc
CDR	Complementary Data Retransmission
CENELEC	European Committee for Standardisation
CIM	Computer Integrated Manufacturing
CRC	Cyclic Redundancy Check
CSMA	Carrier Sense Multiple Access
CSMA/CD	Carrier Sense Multiple Access with Collision Detection
CSMA/BA	Carrier Sense Multiple Access with Bit Arbitration
CRT	Cathode Ray Tube
DCS	Decentralised Control System

SELECTION OF A DEVICE LEVEL FIELDBUS FOR THE PAPER CONVERTING INDUSTRY

NOMENCLATURE

DIN	Deutsches Institut Fur Normung
DLL	Data Link Layer
DP	Decentralised Periphery
EBCDIC	Extended Binary Coded Decimal Interchanging Code
ECC	Error Correction Coding
EIA	Electronic Industrial Association
EMI	Electro Magnetic Interference
EN	European Norm
EOF	End of Frame
HD	Hamming Distance
IDA	Interface for Distributed Automation
IDC	Insulation Displacement Connectors
IEC	International ElectroTechnical Commission
IEEE	International Electrical and Electronic Engineering
IOANA	Industrial Automation Open Networking Alliance
ISA	Instrument Society of America
ISO	International Standards Organisation
ISP	Interoperable Systems Project
IT	Information Technology
JIT	Just In Time
LAN	Local Area Network
LRC	Longitudinal Redundancy Checking

SELECTION OF A DEVICE LEVEL FIELDBUS FOR THE PAPER CONVERTING INDUSTRY

NOMENCLATURE

LSB	Least Significant Bit
MAC	Medium Access Control
MSB	Most Significant Bit
ODVA	Open DeviceNet Vendors Association
OEM	Original Equipment Manufacturer
OSI	Open Systems Interconnection
PC	Personal Computer
PDA	Personal Digital Assistants
PID	Proportional Integral Derivative
PLC	Programmable Logic Controller
PNO	Profibus National Organisation
PROFIBUS	Process Fieldbus
PTO	Profibus Trade Organisation
RFI	Radio Frequency Interference
RS	Recommended standard
SCADA	Supervisory Control and Data Acquisition
SDS	Smart Distributed System
SOF	Start of Frame
STO	Seriplex Technology Organisation
TCP/IP	Transmission Control Protocol/Internet Protocol
TTL	Transistor Transistor Logic
WAN	Wider Area Network

SELECTION OF A DEVICE LEVEL FIELDBUS FOR THE PAPER CONVERTING INDUSTRY

NOMENCLATURE

WWW	World Wide Web

CHAPTER 1

INTRODUCTION

The rapid advance and widespread usage of computers in the form of Information technology (IT) in general and automation in particular, has revolutionized the way in which industry operates [Watson, 2000]. The introduction of communications has enabled industry to adopt specific methods and techniques of manufacture such as 'Just in Time' (JIT).

Such techniques and advances in technology have brought about the requirement for larger, more complex and greater flexible plant, which is necessary to take advantage of economies of scale.

At the heart of the flexible capability of advanced manufacturing is the intelligent production systems, cells and work stations residing on the shop floor. A typical production line consists of a transportation system and several flexible manufacturing cells. The transportation system itself has various sensors and actuators mounted on it to control and monitor its position and to log product information and process controllers. A typical flexible manufacturing cell consists of sensors, actuators, process controllers, manual stations, mechanical linkages, and pneumatic components.

This demand for larger and more complex processes has seen the increase in wiring complexity when using the conventional centralized point to point control system (Chapter 2, Figure 2-4) thus leading to wiring system faults that are not only very difficult to find but also, in terms of overall cost, very expensive. There are other disadvantages with this type of control system for instance, the addition of components requiring the use of a special type of interface have the disadvantage of being very difficult and costly to integrate in an existing system [Farsi & Barbosa, 2000]. One answer is to use proprietary all digital communication networks. The major draw back is that end-users are locked into buying all their equipment from one vendor [leBlanc, 2000].

To overcome these disadvantages, i.e. reduction in the cost of implementation, ease of integration, interoperability and interchangeability of components the use of open fieldbus is a solution that is being increasingly adopted in the automation industry.

Open fieldbus permits several sensors, actuators and control devices to share the same digital communication medium, for example, twisted pair copper wire, coaxial cable, fibre-optic cable and radio. In addition, it facilitates the inclusion of increased intelligence in these devices.

Fieldbus[i] concepts were initially developed in the mid-1980's[ii] with wider acceptance starting in the 1990's - prompted by the advances in technology and ever increasing numbers and diversity of industrial specific products being introduced [Lowe, 2000]. Fieldbus is now universally recognized as being the de facto standard for industrial communications.

Fieldbus has been defined by the International Electrotechnical Commission (IEC) as a "generic" term for "a serial, digital communication network supporting multiple measurement, control and actuation devices on a shared medium" [IEC 1158]. Fieldbus operates in the middle and lower levels of the industrial automation and

[i] The term fieldbus stems from the original ISA SP50 working group and was coined in 1984.

[ii] The International ElectroTechnical Commission formed a working group to look into the development of fieldbus

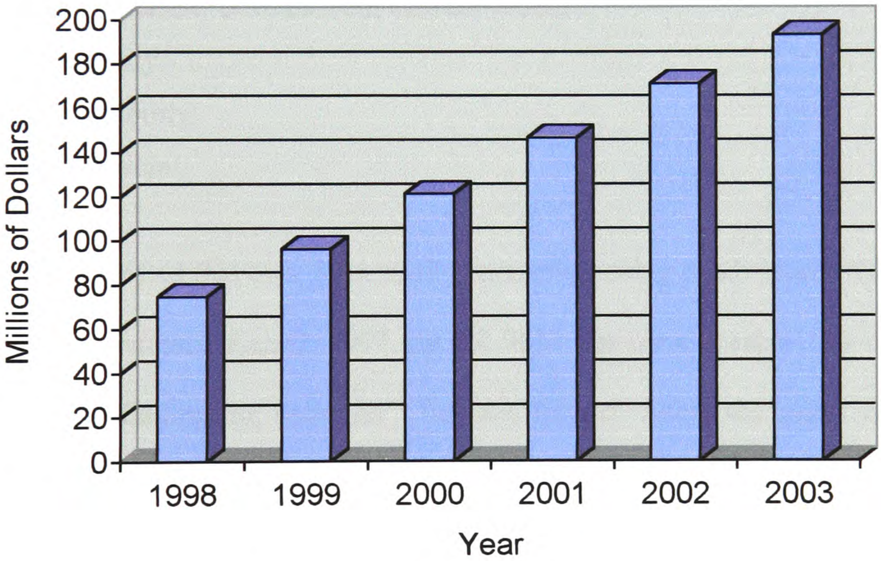
control hierarchy supporting the transfer of both time critical and non-critical data. This study concentrates on open Device level fieldbuses that operate on the lower tier of the industrial automation and control hierarchy (see Chapter 3).

The term "Open system" was defined by the ISA (Instrument Society of America) Dictionary of Measurement and Control 3rd Edition as, an open system is "one that complies with the requirements of the OSI (open system interconnection) reference model in its communication with other open systems". According to other commentators, to be considered open, process automation systems must satisfy and allow for the following criteria [Johnson, 1999].

- The full fieldbus specification must be published and available at a reasonable price.
- Critical ASIC (Application Specific Integrated Circuits) components must also be available, again at a reasonable price.
- Well-defined validation process, open to all of the fieldbus users.
- Interconnectivity: Devices from different manufacturers can be safely connected to the same fieldbus.
- Interoperability: The ability to connect successfully, elements from different suppliers.
- Interchangeability: Devices from one manufacturer can be replaced with functionally equivalent.

There is an argument whether true openness can ever be achieved. This is borne out when one considers the reluctance of corporations to agree an International fieldbus standard with one protocol[iii].

This trend towards open fieldbuses is amply demonstrated when one looks at the growth in memberships of open fieldbus organizations - ODVA (Open DeviceNet Vendors Association) is regarded as the fastest growing network association and over the last four years to April 1999, have recruited over 300 members and 1,498 registered specification holders[iv]. Further evidence of this trend is reflected in the data showing the worldwide sales of fieldbus networks (Figure 1-1).



Note: Data reflects cost of interface only, excluding devices, cabling etc.

Figure 1-1[v] *Total Worldwide Sales of Field Networks*

[iii] The IEC 61158 (Fieldbus standard for use in industrial control systems) standards committee has now agreed to an inclusion of a further seven protocols. There are now multiple non-interoperable protocols. The eight protocols are as follows: IEC Fieldbus, ControlNet, Profibus, P-Net, Foundation Fieldbus, Worldfip, Swiftnet, Interbus

[iv] Information provided by ODVA web site press news April 1999.

[v] Source: Arc (Advisory Research Group) 1999 Market Research of Fieldbuses.

The growing trend towards open fieldbuses, including all the associated potential benefits has prompted companies like Fort James UK Ltd[vi]. to evaluate these more advanced communication networks. Examples of these benefits of fieldbus systems are:

- An overall saving in terms of hardware, maintenance, installation and commissioning costs.
- A reduction in installation and design time
- Cost effective flexibility i.e. modifications, upgrades and refurbishment's
- Enhanced diagnostic/predictive capabilities
- Greater reliability
- Enhanced performance
- Ability to purchase devices from various vendors
- Interoperability
- Interchangeability
- Longer lifecycle

It has been suggested that over 80% of all plants are looking at advanced technologies such as open systems, [Katzel, 1997, pp. 92-96]. For these reasons this study will concentrate on finding the optimum[vii] fieldbus for use within the paper converting industry, in particular for the Fort James plant in South Wales.

Fort James is an amalgamation of Fort Sterling and James River. The company has over 65 manufacturing facilities throughout North America, Western Europe, Russia and China,[viii] employing around 29,000 people. The corporation's main products are

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[vi] Fort James is now owned by the Georgia Pacific corporation as of 1st April, 2001.

[vii] Optimum – due to the overlapping capabilities between fieldbuses it is highly unlikely that one bus will fulfill all the necessary criteria.

[viii] Fort James Corporation 1997 annual report

toilet tissue and kitchen towels. The product starts as raw paper pulp, which then passes through various stages of processing before being transformed into the grade and colour of paper dictated by customer demand. Once this process is complete the paper reels, which weigh approximately 3 tonnes each, pass into the converting department where they are rewound to the required diameter and perforation length, at which point the finished product is packaged and shipped to the customer.

Prior to 1995, all Fort James UK Ltd sites employed either relay logic or, in the majority of cases, conventional centralized control systems for machine control. During 1995, the first proprietary network (Rockwell's[ix] Remote I/O) was installed as part of a retrofit/upgrade project. The prime reason behind the decision to use proprietary network was to reduce both installation time and wiring complexity[x]. The success of the project, both in terms of its ease of installation, reliability and less complex wiring has led to approximately two thirds of all projects i.e. new machinery, upgrades, retrofits, within Fort James UK Ltd to incorporate a proprietary network.

1.1 TOOLS AND TECHNIQUES

In order to choose the optimum fieldbus from the 200 or so different fieldbus[xi] systems currently on the market [Lane, 1997], several techniques and tools are required. One such technique used in this project for rational decision making was developed in 1965 by Dr C. H. Kepner and Dr B.B.Tregoe and is referred to as Kepner Tregoe. This technique is used to generate a:

[ix] Formerly Allen-Bradley

[x] No formal calculation was made of the actual cost savings involved as installation time was the prime consideration. Installation and commissioning time was reduced by approximately 1 week.

- Systematic,
- Informed,
- Balanced
- Non-biased
- Two-dimensional approach to decision making.

This technique has been used by many large organizations throughout the developed world. N.A.S.A being one such organization.

In addition, a software tool will be used to assess one of the main benefits of fieldbus i.e. cost reduction. The software developed by Rockwell calculates the comparative installed costs of three different networks.

To facilitate the evaluation of potential risks associated with a newly selected product. A small scale fieldbus trial will be carried out on a converting rewinder line using Rockwells fieldbus starter kit.

1.2 AIMS AND OBJECTIVES

The aims and objectives of this research are:

- To select the optimum device level fieldbus for machine control within the paper converting plant of Fort James UK Ltd.

- To arrive at a balanced, un-biased choice, using the Kepner Tregoe[xii] systematic approach to decision analysis.

[xi] There are 22 protocols in Europe alone

[xii] As Kepner Tregoe Decision Analysis is a crucial part of the selection process. A copy of the manual is included for reference in Appendix A.

- To use a software tool to assess the main benefits of fieldbus
- To carry out a small-scale trial to facilitate the evaluation of risk with a newly selected product.
- To make recommendations either to implement open fieldbus technology or remain with the status quo.

1.3 OUTLINE OF STUDY

Chapter 2 - reviews the development and future direction of fieldbus. This is necessary in order to assess any potential risk that may jeopardize the recommendation of the selected fieldbus.

Chapter 3 - gives a broad outline of the fundamentals of a fieldbus system. Included in this chapter is sufficient detail to set the technical/performance criteria necessary for the selection process set-out in Chapter 4.

Chapter 4 – deals with the selection of the optimum fieldbus. It evaluates the identified alternatives against specific criteria (composed from the detail contained in Chapter 3) and against the requirements of a paper converting plant. Also included is a potential risk analysis to ensure that installing the proposed fieldbus has no unforeseen adverse consequences. A cost comparison software tool is used to evaluate any cost reductions associated with the selected fieldbus compared to that of the existing networks used in the paper converting process.

Chapter 5 – sets-out in detail the fieldbus evaluation trial i.e. method, results and conclusions. The fieldbus trial is used to establish whether or not the findings from the previous chapter are accurate, thus alleviating further the risk.

Chapter 6 – contains the conclusions, recommendations and further work drawn from this study.

CHAPTER 2

DEVELOPMENT AND FUTURE OF FIELDBUS

This chapter reviews the development and possible future direction of fieldbus. In the first instance it has been necessary to look into the limitations and shortcomings of the traditional machine control technology of the past, before moving on to discuss modern day programmable controllers and how their flexibility influenced, amongst other things, the economics of today's manufacturers. The latter section of this chapter is concerned with communications, fieldbus itself and finally the future direction of this advanced technology.

2.1 TRADITIONAL MACHINE CONTROL.

Prior to the programmable controller in 1974, control systems with input/output (I/O) devices were predominantly based around the Electro – mechanical relay [Ball, 1997]. Sensing devices positioned on the machine detected machine control changes. The devices, for example limit switches, would detect movement by contact with the machine. The contact would complete a circuit within the limit switch. The completed circuit would send a signal to the control panel. The signal would then energize a relay, which in turn would complete another circuit, so providing power to an output device. (Figure 2-1).

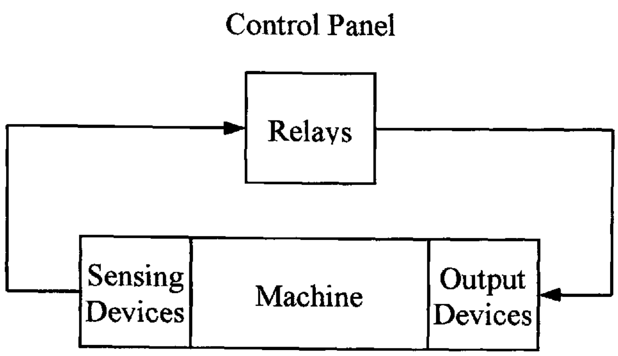


Figure 2-1[i] *Traditional Control System*

2.2 PROGRAMMABLE CONTROLLER

The Hydramatic Division of the General Motors Corporation specified the design criterion for the first programmable controller in 1968 [Liptak, 1995]. The first programmable controller was introduced in 1969 by Dick Morley, and sold by MODICON (MOdular, DIgital, CONtroller)[ii]. Table 2-1 lists some of the milestones in the development of PLC's.

The primary goal of programmable controllers was to eliminate the high costs associated with inflexible, relay controlled systems. The specification required a solid state system with computer flexibility suited to survival in the industrial environment, easy programming and maintenance by plant engineers and technicians, and reusability [Bryan, 1997].

[i] Source Allen Bradley symbols Library

[ii] An interview by the author with Dick Morley revealed that whilst General motors had produced a specification for a PLC this was completely divorced from his own , which was also produced in 1968.

Table 2-1[iii] *History of Programmable Logic Controller*

History of programmable Logic Controllers (PLC)	
1968	Design of PLC's developed for general motors corporation to eliminate costly scrapping of assembly line relays during model changeovers.
1969	First PLC's manufactured for automotive industry as electronic equivalents of relays.
1971	First application of PLC's outside the automotive industry
1973	Introduction of "smart" PLC's for arithmetic operations, printer control, data control, data move, matrix operations, CRT interface etc.
1975	Introduction of analogue PID (proportional, integral, derivative) control, which made possible the accessing of thermocouples, pressure sensors etc.
1976	First use of PLC's in hierarchical configuration as part of an integrated manufacturing system.
1977	Introduction of very small PLC's based on microprocessor technology.
1979	Integration of plant operation through a PLC communication system.
1980	Introductions of intelligent input and output modules provide high-speed, accurate control in positioning applications.
1981	Data highways enable users to interconnect many PLC's up to 15,000feet from each other. More 16 bit PLC's become available. Other graphic CRT's are available from several suppliers.
1982	Larger PLC's with up to 8192 I/O become available
1983	"Third party" peripheral, including graphic CRT's, operators' interfaces, "smart" I/O networks, panel displays and documentation packages, become available from many vendors.
1994	Introduction of Soft PLC
1998	Introduction of PLC and motion intergrated into the same CPU

[iii] Source:Liptak, G, B.: Instrument Engineers Handbook 3rd Edition, PLC's and other Logic Devices, p722

In general, the introduction of PLC (Programmable Logic Controller) hardware and software provided more system flexibility, greater data processing capability, and the possible development of communication systems. Figure 2-2 shows the basic structure of a PLC.

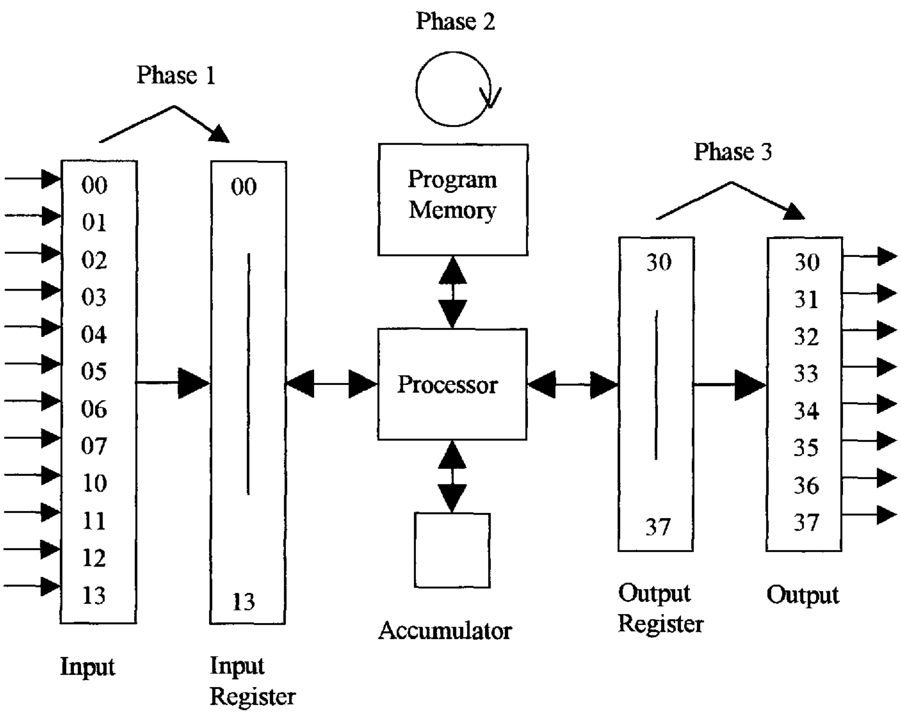


Figure 2-2[iv] *Basic Structure of a PLC*

2.3 COMMUNICATIONS

The first digital data communications enabled computers to communicate with each other via a central Node or star like net, with point to point connections based on

[iv]Source: Levine, S. W. The Control Handbook. CRS Press, p353

RS232. Advances in technologies paved the way for the more favoured Tree structure network - the main differences being that users are connected to the same cable and transferred data are time-multiplexed [Matteo, 1999].

As communication protocols improved and the costs of communications reduced, it became cost effective to connect simple devices directly to a network [ODVA, 1999] so eliminating expensive hardwiring and providing, greater reliability, flexibility and quicker commissioning times. Figure 2-3 shows one possible interpretation of the Evolution in Control Theory [Matteo, 1999].

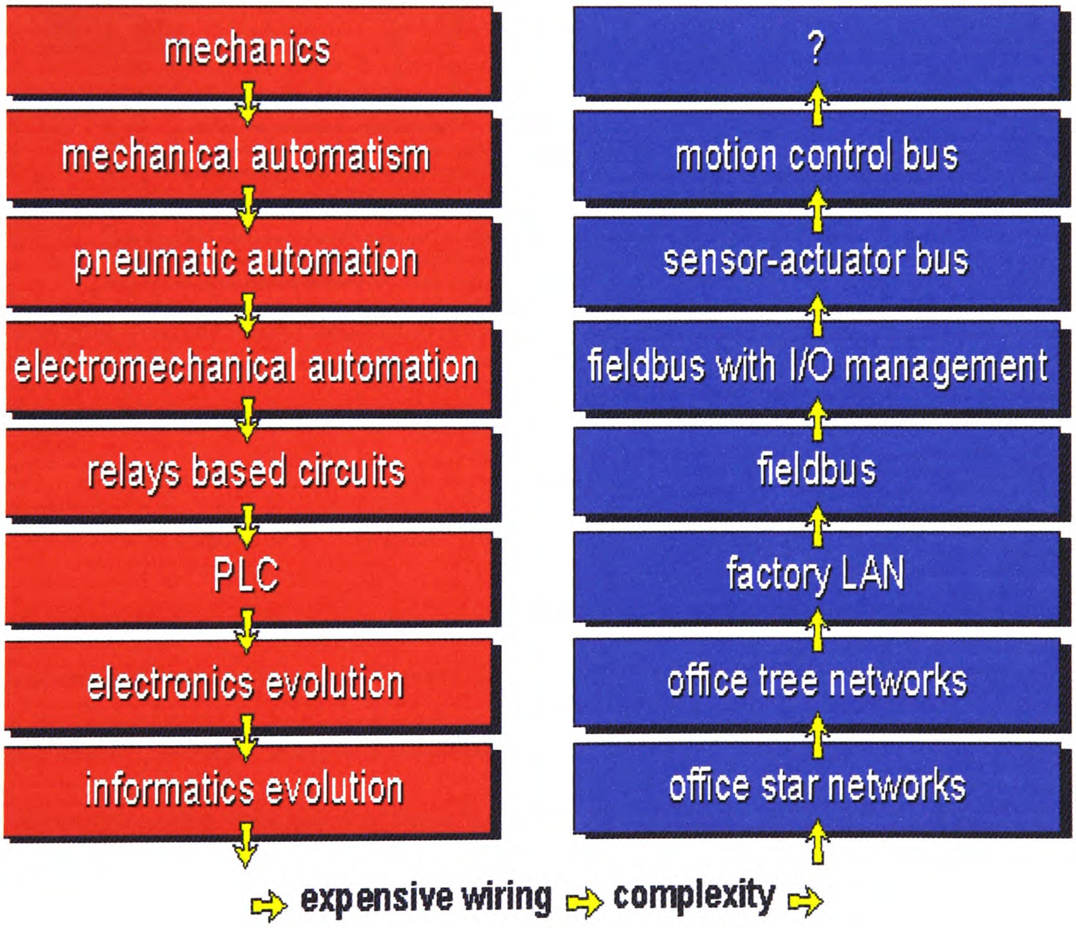
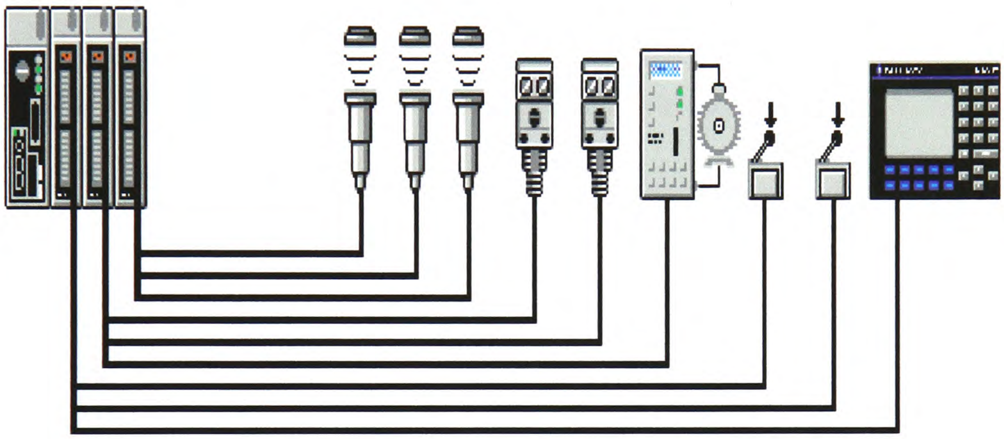


Figure 2-3[v] *Evolution of Technology in Control Theory*

[v] Source: [Matteo, 1999]

2.4 FIELDBUS

Around twenty years ago[vi] most industrial vendors introduced proprietary Remote I/O and/or peer to peer networks that interconnected controllers, remote I/O racks and some more complex stand-alone control equipment, such as operator interfaces, drives and motion controllers. The intention was to reduce wiring costs and provide an



alternative to the traditional parallel wiring of I/O (Inputs/Outputs). (Figure 2-4)

Figure 2-4[vii] *Typical Control System using Parallel Wiring*

Open fieldbuses (Figure 2-5) were derived originally from proprietary networks[viii]. Customer pressure played a significant part in the move towards open networks [Johnson, 1999]. Examples of these include:

[vi] This approximation was derived by looking at the dates of introduction of several of the leading manufacturers of proprietary networks i.e. Rockwell's Remote I/O year introduced 1980.

[vii] Source Rockwell's symbol library.

- ASI (formerly SINEC S1 now managed by AS- Interface) developed by Siemens, introduced in 1993.
- Profibus (Formerly SINEC L2 managed by PTO and PNO) developed by Siemens, introduced in 1994.
- SDS by Honeywell (Administered by Honeywell but supported by vendor and user groups), introduced in 1994.
- DeviceNet (managed by the ODVA) and developed by Rockwell, introduced in 1994.
- ControlNet (managed by ControlNet International) and developed by Rockwell, introduced in 1996.

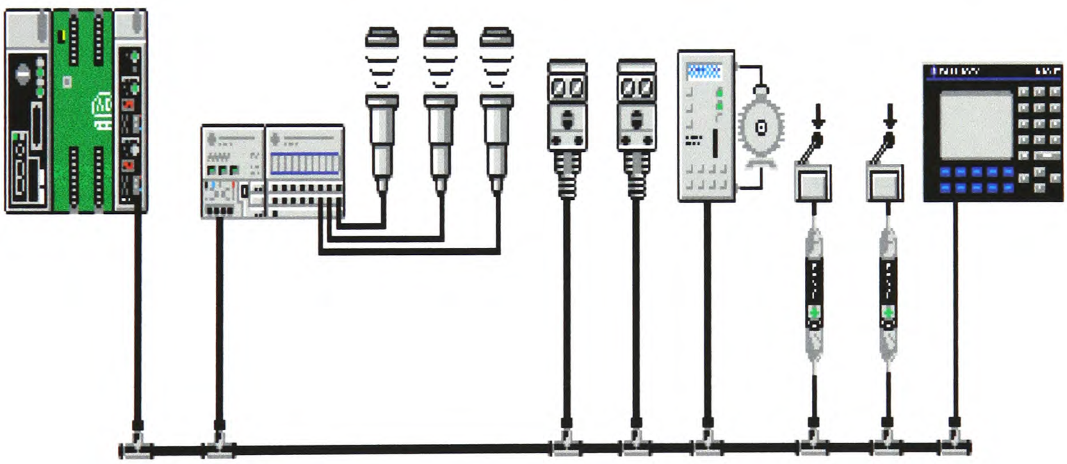


Figure 2-5 [ix] *Typical Fieldbus Cabling*

[viii] Whilst this is true in the main around the same time the programmable controller was introduced in 1974 a product called Directrol was introduced. This was the first device level fieldbus system. It was ahead of its time and ceased production in the early 1980's.

The development of the open architecture of fieldbus offers the end user many benefits,[x] as follows:

- The I/O resides within the field device, as opposed to being attached to the main controller, and as such reduces the PLC or DCS hardware requirements. This property also reduces the need for large control cabinets to house such equipment and associated connecting hardware.

- As all devices share the same communication medium there is a significant reduction in the amount of cabling required. As cabling is reduced[xi], the need for junction boxes, control panels and large cabling runs is eliminated. These advantages, along with those discussed in the point above equate to a direct cost saving. Cost savings are routinely cited at 50% or higher on wiring, panels, and junction boxes [Peterson, 1998].

- Reductions in the complexity of fieldbus systems result in the need for fewer system drawings and project design time.

- Due to greater reliability, downtime and production losses are reduced. The decreased complexity, compared to that of conventional systems, superior diagnostic and fault finding procedures, means the overall need for maintenance is less.

[ix] Source Rockwell's symbol Library

[x] a set of strategic benefits can be found in the fieldbus standard IEC 61158.

[xi] Installation costs are further reduced due to the fact that fieldbus is a multi drop rather than point to point system, therefore offering a 5:1 reduction in field wiring expense [Rolf, 1998].

- The architecture of the bus system, coupled with a decrease in the amount of components used in fieldbus systems, means that future modifications, upgrades and refurbishment can be carried out at very little expense.

- The open specification of fieldbus makes possible the connection of products from different manufacturers. This will be further enhanced whenever there is a single worldwide protocol for process control.

- System performance is enhanced due to the ability of fieldbus technology to enable two devices to communicate directly with each other (peer-to-peer) rather than via the control system.

2.4.1 Control Network Hierarchy

Fieldbus was designed to fulfill the requirements of the Lower and Middle tier of the Industrial Control hierarchy, referred to as the Device and Control layer respectively, the third layer being the information layer (Figure 2-6).

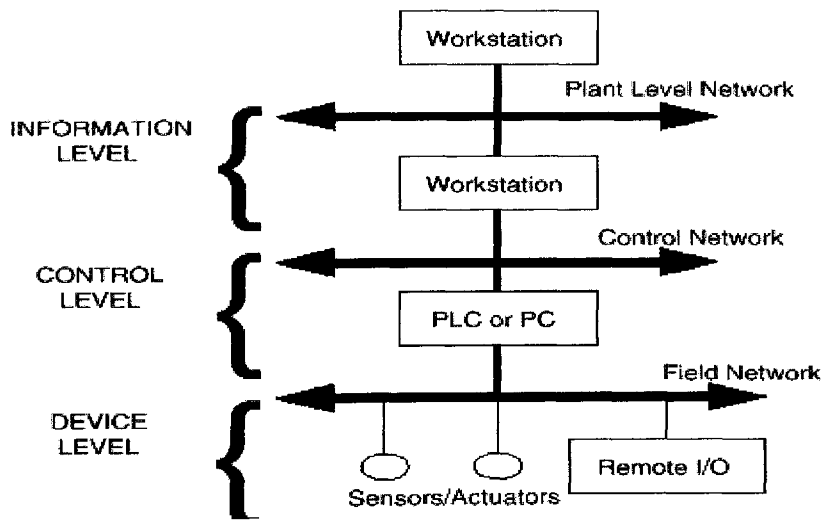


Figure 2-6 *The Control Network Hierarchy*

Although the concepts governing each network and each layer are the same, the task execution varies significantly, thus necessitating the requirement for specialist networks. There is not one general fieldbus capable of meeting all demands, many buses having been developed with overlapping capabilities (Figure 2-7).

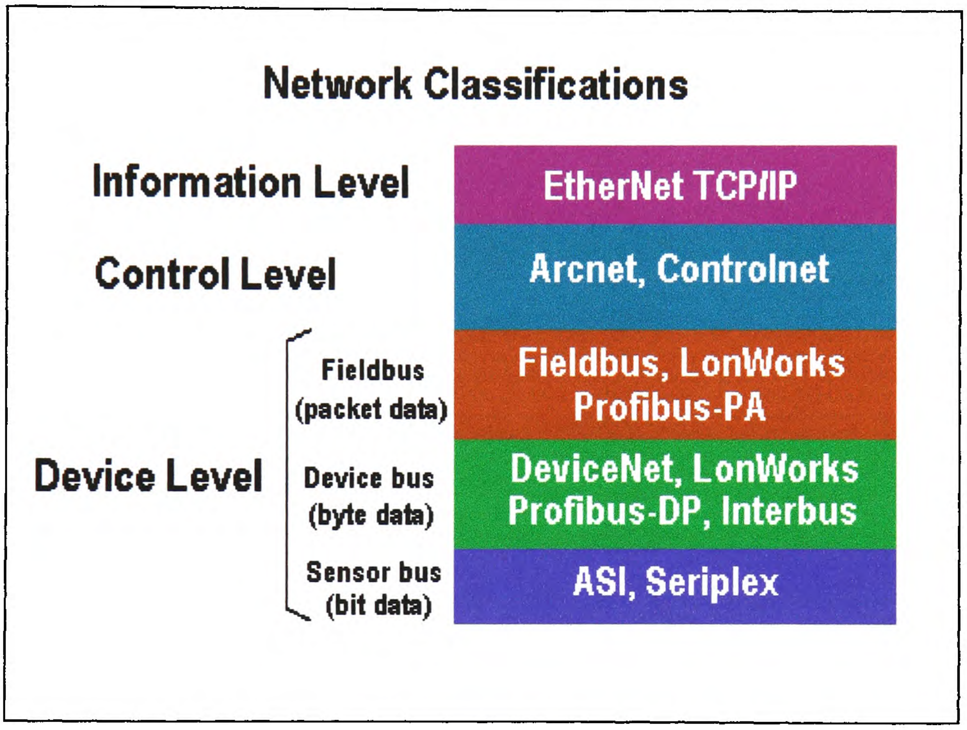


Figure 2-7[xii] *Network Classifications*

The characteristics of the three level hierarchical models are discussed below:

- At the highest level is the information layer, this tending to be plant wide, use large data packets, carry PC- based interfaces and having traditionally enjoyed a high degree of interoperability. Numerous products are commercially available, accessible, and low in cost. Ethernet TCP/IP has clearly been the most

[xii] Source: figures 2-7, 2-8, 2-9, 2-10, 2-13 [Pinto, 2000]

prominently used network at this level. Ethernet is gaining wide acceptance, even at the lower levels, due to its well-established performance, commercial proliferation and decreasing costs.

- At the control layer small to medium size packets of data and faster response times are required. This level generally finds multiple PLC's talking to one another. Due to its critical performance requirements this level must be fast, reliable and, up until recently, intolerant of openness. The introduction of a deterministic, repeatable open protocol for time critical I/O data and peer to peer messaging is changing the face of midlevel networking. ControlNet and Arcnet are prime examples of this type of network.

- The device layer is split into three levels, sensor, device and field. Below is a summary of each of these levels.

  - The lowest level are the sensor networks which communicate bits of I/O data associated with the status of a sensor, usually restricted to on/off status. This is often limited to four or eight bits per Node; these networks cannot transmit words of data.

  - The Device networks provide analogue and digital support and communicate bits of I/O data associated with the status of a device (sensor actuator). This can include diagnostics bits as well as status bits. Device networks are also capable of sending words of data in limited numbers per transmission. Data strings of more than eight or nine words can be segmented over several transmissions.

- The field networks are characterized by long streams of data. Status bits of devices (if available) are embedded in words that have to be decoded to extract the information.

2.5 FUTURE

At the present rate of change it is difficult, if not impossible, to predict what changes will occur over the next ten years.

There are three laws that are generally accepted as governing the spread of technology:

- **Moore's Law:** formulated by Gordon Moore of Intel in the early 1970's-"the processing power of a microchip doubles every 18 months; corollary, computers become faster whilst the price of a given level of computing power halves every 18 months".
- **Gilder's Law:** proposed by George Gilder–" the total bandwidth of communication systems triples every twelve months". New developments seem to confirm that bandwidth availability will continue to expand at a rate that supports this Law.
- **Metcalfe's Law:** attributed to Robert Metcalfe, originator of Ethernet and founder of 3COM: This law states "the value of a network is proportional to the square of the number of Nodes"; therefore as a network grows so the value of being connected to it grows exponentially, while the cost per user either reduces or remains the same.

Kurzweil [Kurzweil, 1999] extrapolates Moore's Law to predict that by the year 2030 there will be the emergence of machines with intelligence exceeding that of human beings. On the other hand, Gordon Moore believes this to be impossible as he himself predicts that Moore's law, as applied to integrated circuits, will no longer be applicable after 2017 – at which time IC geometry will be approximately one atom thick. The time frame may be expanded by a further twenty years with the recent announcement by Lucent that they could manufacture multiple transistors vertically in silicon. Other technologies such as bio chips and nano-technology [Drexler, 1986] will come to the forefront, moving the equivalent of Moore's law inexorably forward.

Looking at a shorter time frame, Kurzweil and many other commentators predict that within the next decade products, such as those listed below, will become commercially available.

1) Intelligent I/O "appliances"
2) PLCs to PCs and intelligent I/O
3) Self organizing complex adaptive systems
4) Industrial Ethernet as a seamless network from Device to PC
5) Industrial wireless Network

1) Intelligent I/O appliance

With the significant reductions in the price of processing power and memory, it is predicted that embedded processors will penetrate and populate virtually every I/O point – so producing an intelligent "appliance". The expression "appliance" entails information residing inside the device which relates to its history, part number, place of purchase, time installed, by whom, key characteristics, specifications operating instructions, diagnostics, availability of spares, repair instructions etc. At present this information resides in printed documentation. Figure 2-8 illustrates the concept of a smart "appliance".

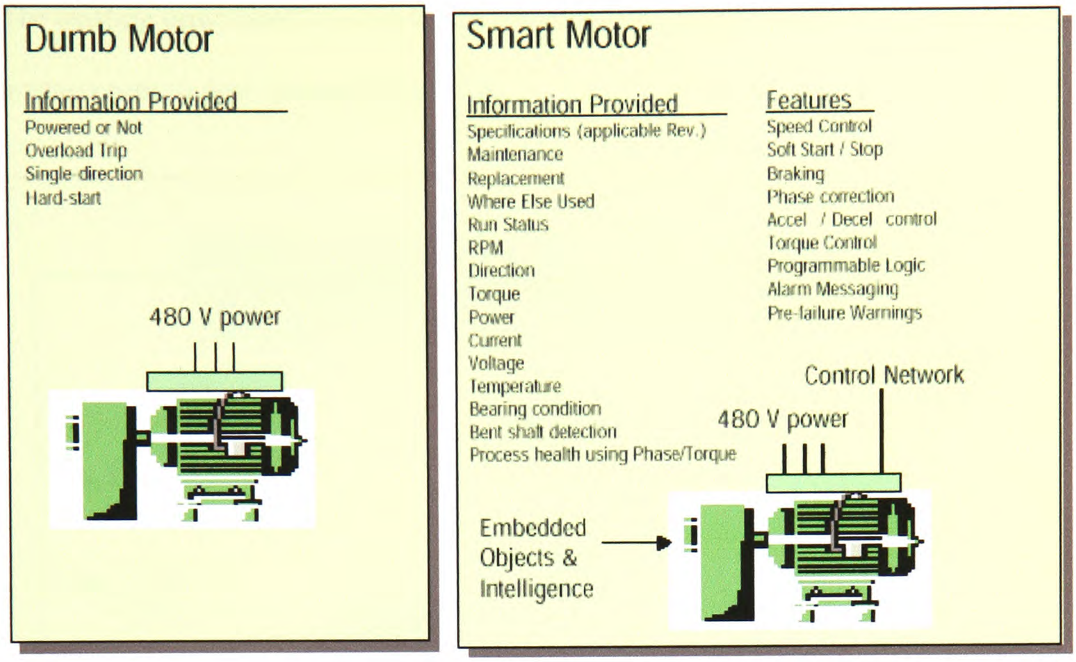


Figure 2-8[xii] *Smart "Appliance"*

2) PLCs to PCs and Intelligent I/O

Within the next few years personal computers (industrial and embedded equivalents) will replace programmable controllers in all but the smallest applications. This is primarily a result of the higher level programming capabilities of PCs. PLCs will serve as machinery controls and front-end I/O processors for device level networks. Larger control systems (DCS) will eventually yield to field-based intelligent I/O systems.

3) Self organizing Complex Adaptive Systems

The next ten years will see a move away from fully deterministic hierarchical control architectures. The reason for this move are self evident, hierarchical deterministic architectures are unable to cope with systems beyond 50-100,000 points, many large factories and process plants are already expanding beyond that level of complexity.

The existing centralized command and control system will be replaced by a rule-based hostless peer to peer system (Figure 2-9).

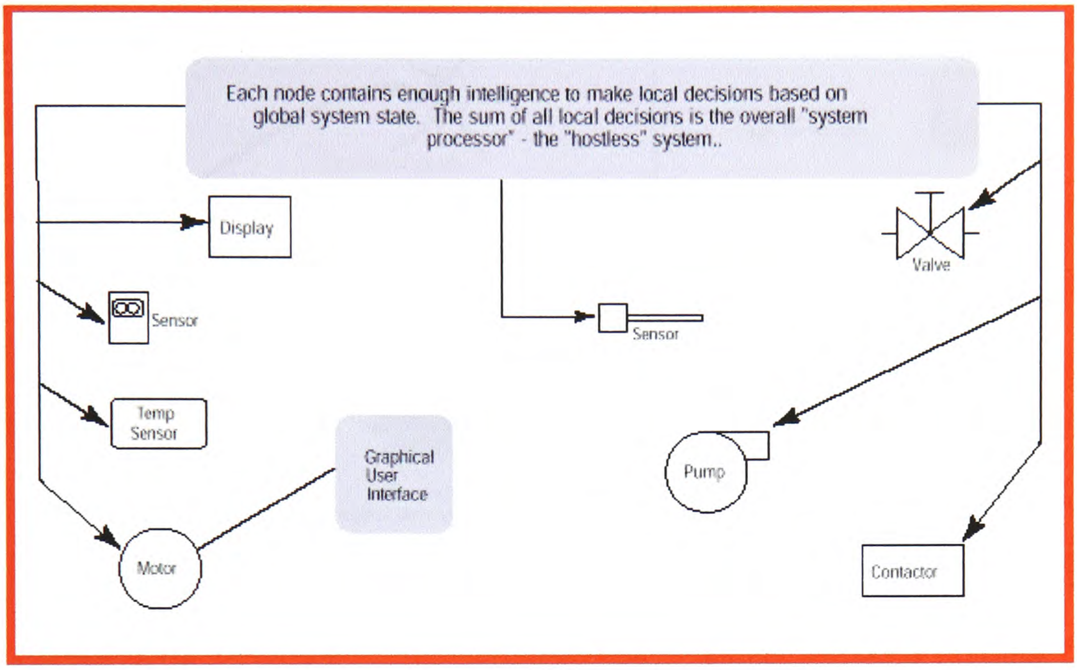


Figure 2-9[xii] *Ideal Architecture for Complex Adaptive Control*

Each I/O point will contain intelligence, whilst connected control will be handled locally through intelligent peer to peer communications between the sensors and actuators, without intervention from an external host processor.

If Metcalfe's law is true (effectiveness increases exponentially), the ever increasing connectedness of peer to peer control systems will result in an intrinsically different kind of operation – Complex Adaptive Systems (CAS).

Complex Adaptive Systems will yield significant advances through reduced software, faster and easier installation, robust performance, vastly improved flexibility, capability to handle very much larger I/O point counts.

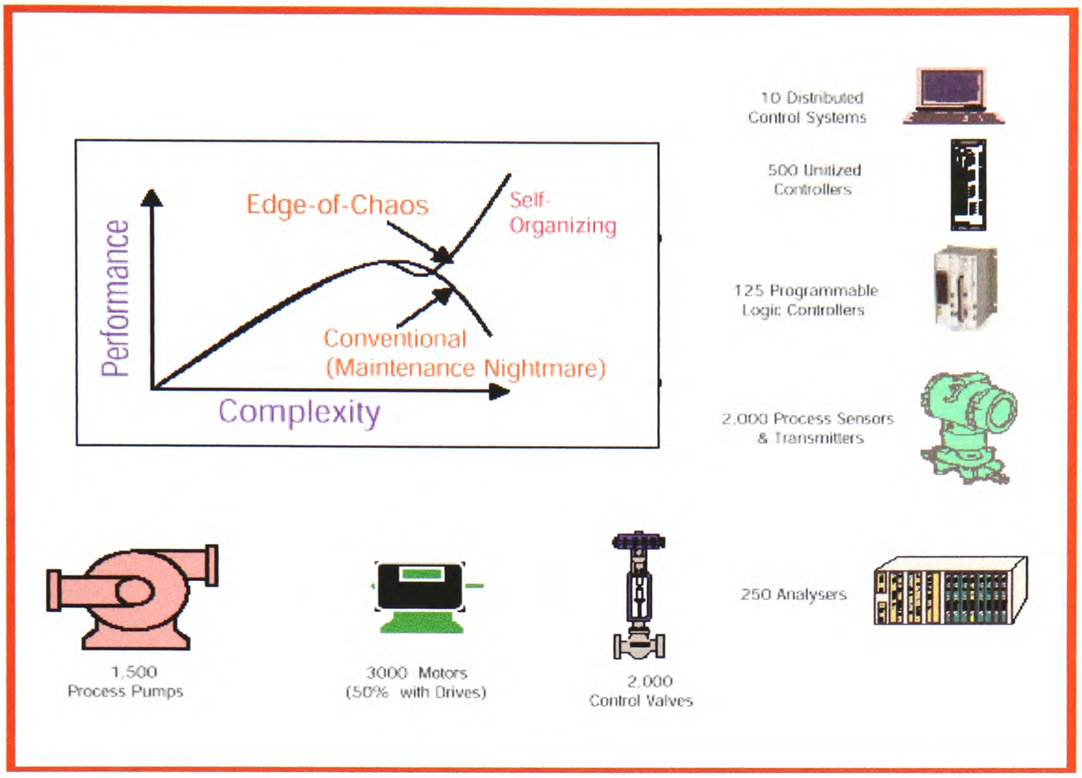


Figure 2-10[xii] *Comparison between Conventional and Self Organizing Complex Adaptive System*

As a result of the emergent behavior and self-organizing capabilities (Figure 2-10) CAS will have the ability to achieve much higher levels of performance.

Work on artificial life and genetic algorithms is already being carried out at places like Santa Fe Institute. Morley and Moody predict that over the next decade the results from these studies will begin to be evident in factory automation and process controls [Morley and Moody, 1999].

4) Industrial networks

It is the opinion of many commentators that the next de facto fieldbus standard will be industrial Ethernet. Advisory Research Group (ARC) also predicts a rapid growth in Industrial Ethernet [ARC, 1998]. Figure 2-11 Illustrates ARC predicted market growth by bus type. Industrial Ethernet will provide a cheap, easy to use network offering a direct connection from device to PC (personal computer), thus eliminating the need for bridges and gateways. During the November 2000 SPS/IPC/Drives show held in Nuremberg, representatives of IAONA- Europe (Industrial Automation Open Networking Alliance), Open DeviceNet Vendors Association (ODVA), and Interface for Distributed Automation (IDA) group discussed pooling their efforts for the advancement of Ethernet and TCP/IP (Transmission Control Protocol/Internet Protocol) technology [Angus, 1999], [Hulsebos, 2000].

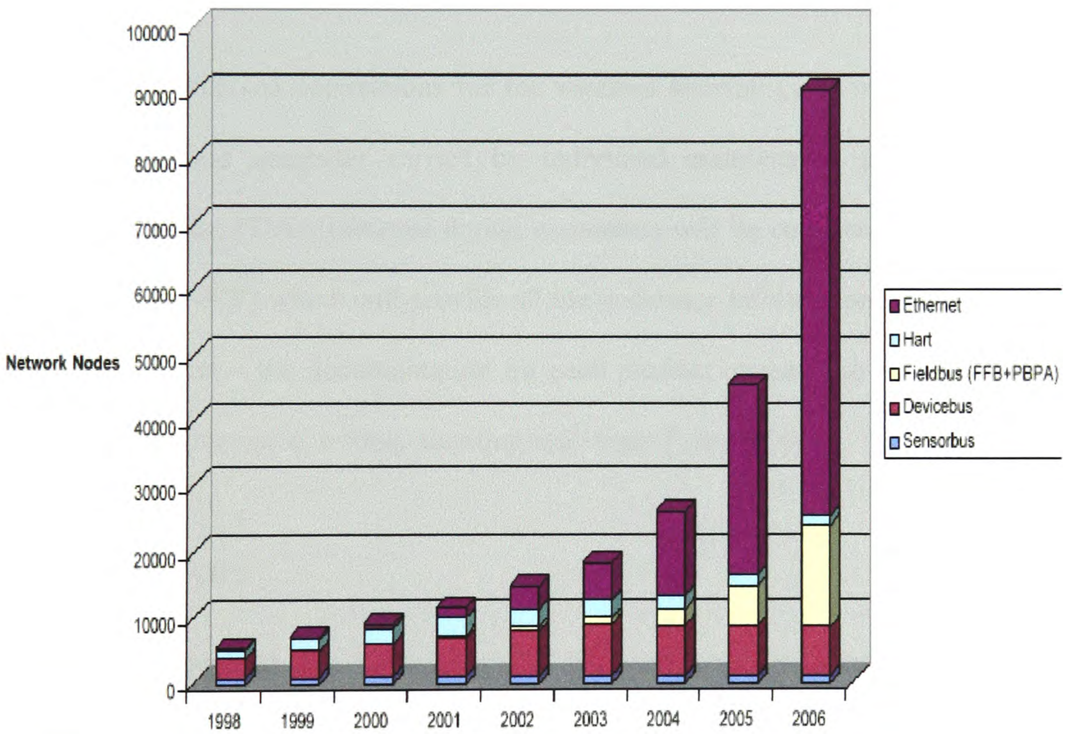


Figure 2-11 *Predicted Market Growth by Bus Type*

5) Wireless connections

With the inception of third generation wireless connectivity (including a new local area network technology called "bluetooth[xiii]") virtually all I/O connections can be simply, effectively and economically connected to become part of the new complex adaptive system architecture.

Within the factory, or process environment, the fear of tampering is an inhibitor to the use of a wireless operated system; although with the use of modern encryption techniques this fear has been virtually eliminated in the banking industry, stock market and other high value applications.

One of the perceived applications for the wireless technology in industry will be a portable wireless computer carried by individual maintenance personnel. These portable wireless PDAs (personal digital assistants) will be connected via the World Wide Web (WWW) which will provide all the necessary information required to read the local objects – the documentation for each product or machine – as well as for plant wide maintenance, trouble-shooting and repair [Caro, 2000].

2.6 SUMMARY

Fieldbus has evolved as a consequence of the ever increasing demands for greater reliability, flexibility and lower installation times. These were unobtainable whilst point to point wiring had to be used. The increasing development and lowering costs of communications provide a perfect platform from which to develop what is known today as 'fieldbus'.

[xiii] IEEE 802.15 standard

Whilst fieldbus technology is not new, acceptance of fieldbus had been slow, particularly in the UK (Figure 2-12). A survey of 207 companies per region from various sectors was carried out over a three year period to ascertain the adoption rate of countries to open digital communications.

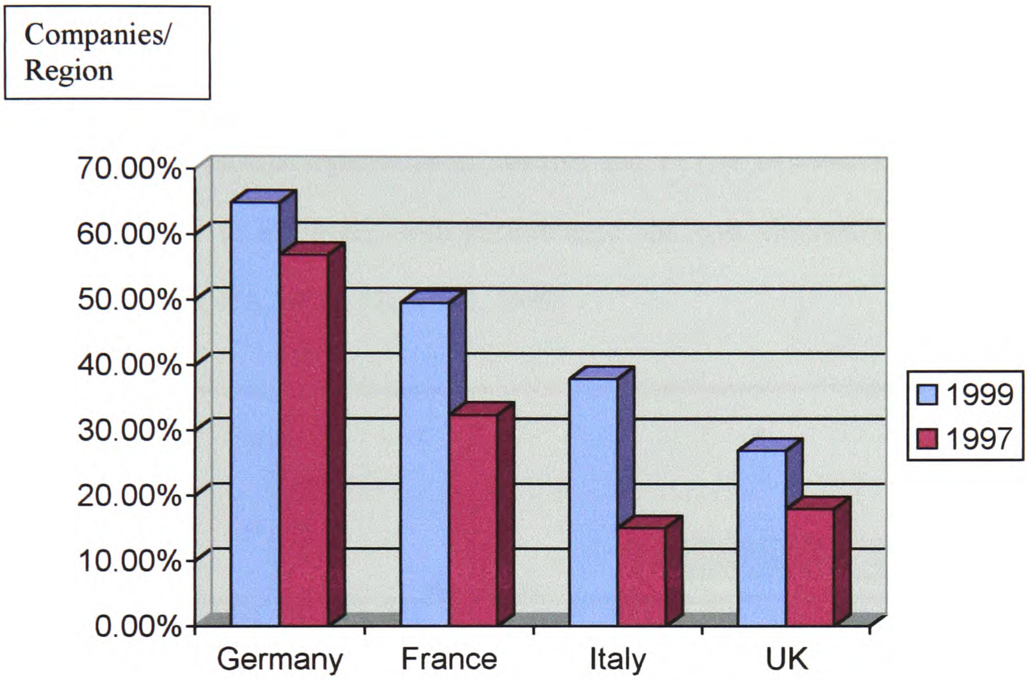


Figure 2-12[xiv] *Adoption Rate of Countries to Open Digital Communications*

The advances in technology, introduction of an ever-increasing diversity of products and support from major PLC manufacturers, examples being Siemens and Rockwell, over the last few years have piloted the universal acceptance of fieldbus as the de facto standard for industrial communications.

During the next few years the impact of Moor's Law, operating in conjunction with Gilders Law and Metcalf's Law, will spread steadily through the industrial

[xiv] Source: IMS, 1999 survey

automation environment. This inexorable advance in technology will make possible the inception of products such as intelligent I/O appliances and self-organizing complex adaptive systems[Pinto, 2000] .

It is envisaged that industrial networks will see the fieldbus standard being replaced by the practical emergence of several parallel, and perhaps overlapping standards, each suited to a particular industry and/or environment (Figure- 2-13). Over the next few years the industrial extensions to Ethernet and TCP/IP will become the standard for connectivity at all levels, with performance and cost eliminating the need for alternatives [IAONA,2001], [Turnbull, 1999].

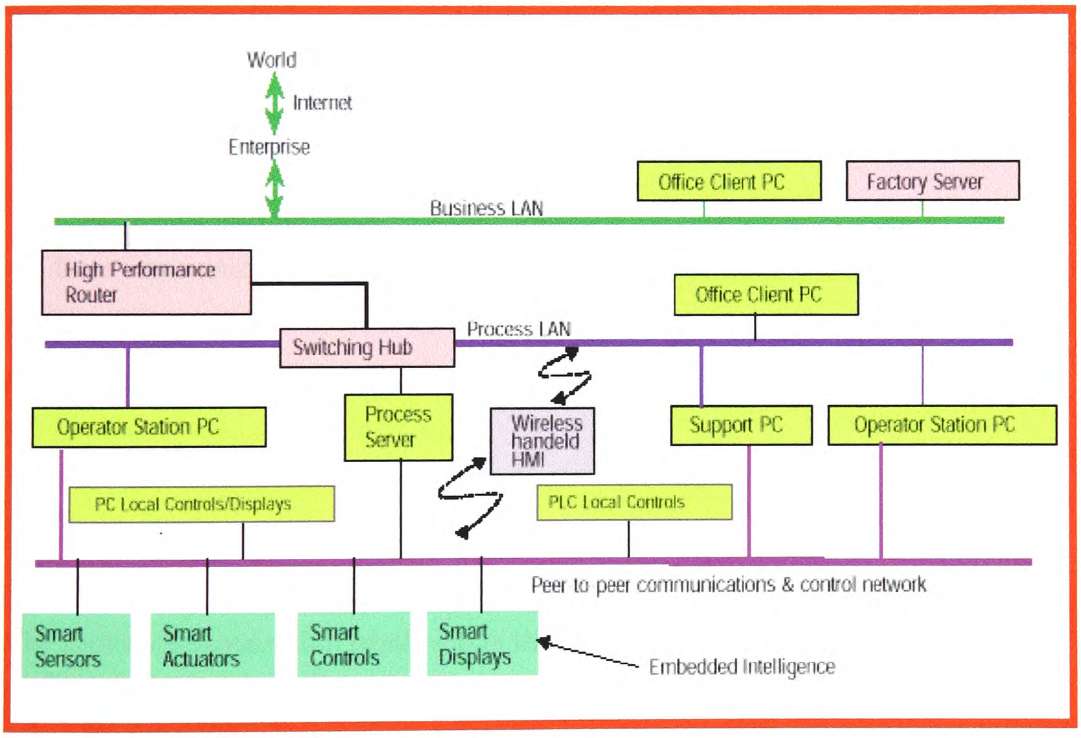


Figure 2-13[xii] *Control Networks for the Next Decade*

Chapter 3 discusses in detail the fundamentals of fieldbus systems. The findings from Chapter 3 will be utilized in the Kepner Tregoe's decision analysis process in Chapter 4 to help form the criteria by which the optimum fieldbus can be selected.

CHAPTER 3

THE FUNDAMENTALS OF FIELDBUS SYSTEMS

In order to set the technical/performance criteria by which to select an optimum fieldbus it is necessary to discuss in some detail the fundamental aspects of fieldbus systems.

It is important that one has a broad overview in order to appreciate the common terminology when discussing and using a fieldbus system. Not only is it necessary to have a good overview but also an understanding of the functionality and interaction of the main building blocks that make up a fieldbus system, these being:

- Communications protocol
- Data communications
- Interfacing
- Topology
- Medium access control methods
- Error detecting and checking mechanisms
- Addressing approaches
- Standards

The above are explained in depth within the chapter

3.1 OVERVIEW

A Fieldbus[i] is a digital, bi-directional, communication system where a device transmits encoded data sequentially over a common medium as a series of logical 1's

[i] Fieldbus has been defined by the International Electrotechnical commission (IEC) as a "generic" term for a serial, digital communications network supporting multiple measurement, control and actuation devices on as shared medium.

and 0's. This data can be routed along the bus in several ways, the most common being Master/Slave or Peer to Peer. In the Master/Slave method all information is routed through the Master controller. The central controller (Master) controls the bus and the devices (Slaves), which can only communicate with the Master, not with each other. The Peer to Peer method is where a device will communicate directly with another device without requiring re-transmission by the Master.

The connection between an addressable device and the bus is known as a Node. The way in which these Nodes are connected to the Bus is referred to as the 'topology'. The topology can be Spur, Ring or Tree.

Figure 3-1 below shows a simple fieldbus system.

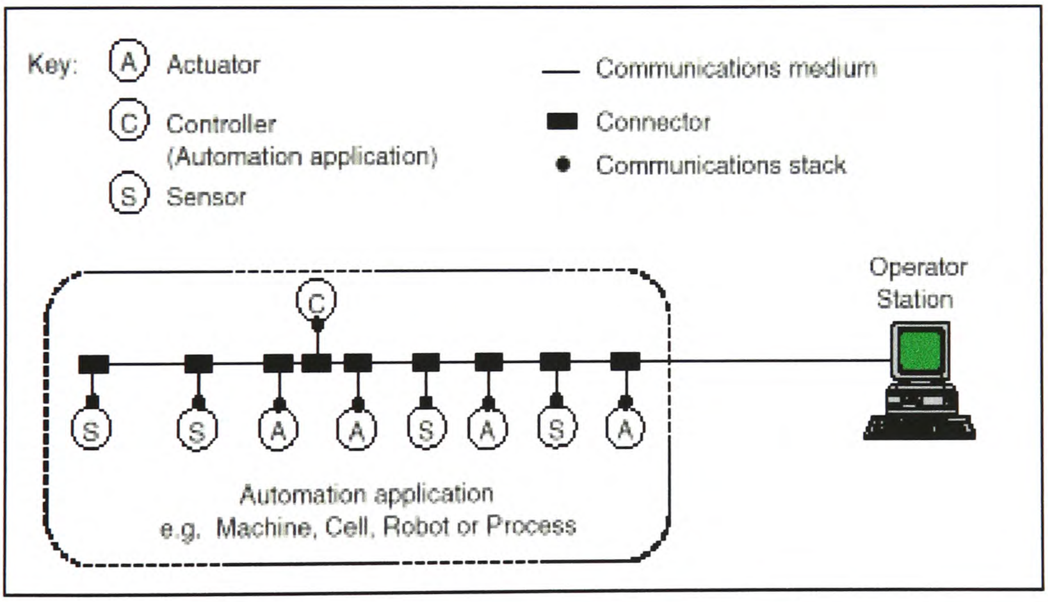


Figure 3-1[ii] *Simple Fieldbus System*

[ii] Source: BSI, Guide to the evaluation of fieldbus protocols

All devices are coupled to a common communications medium (often referred to as the Bus). The media commonly used are twisted pair copper wire, coaxial cable and fibre optic cable. Each device, or I/O module, has embedded within it a device that can support both communications and logic. These ASICs (Application Specific Integrated Circuits) are often referred to as the 'stack' [Bazany, 1997, pp. 88-90]. In addition to the stack the fieldbus device contains the user's automation application processes-this is the software/firmware and hardware that performs the device's primary functions (Figure 3-2).

3.2 COMMUNICATION PROTOCOL

In order to achieve reliable and coherent interNode communications, the international Organization for standards (ISO) devised a set of rules defining the way in which fieldbus devices communicate. This is called the "Open Systems Interconnection basic reference model", or "OSI model". These rules are not meant to be a standard but a reference model. The following sections discuss the features and functions relevant to device level fieldbus systems.

3.2.1 ISO/OS1 Reference Model

The OSI/ISO Reference Model is a framework that was devised and released in 1978[iii] by ISO[iv] [Tagney and O'Mahoney, 1996] to support the development and implementation of open communication protocols.

[iii] In 1984 a revised copy of this document was published and became an international standard: ISO/IS/7498.

[iv] The ISO is not an acronym for International Organization for standards. ISO is a word, derived from the Greek isos , meaning "equal"

The OSI Reference Model (Figure 3-2) is made up of a set of 7 layers known as a 'stack'. Each transmitting and receiving device requires a stack.

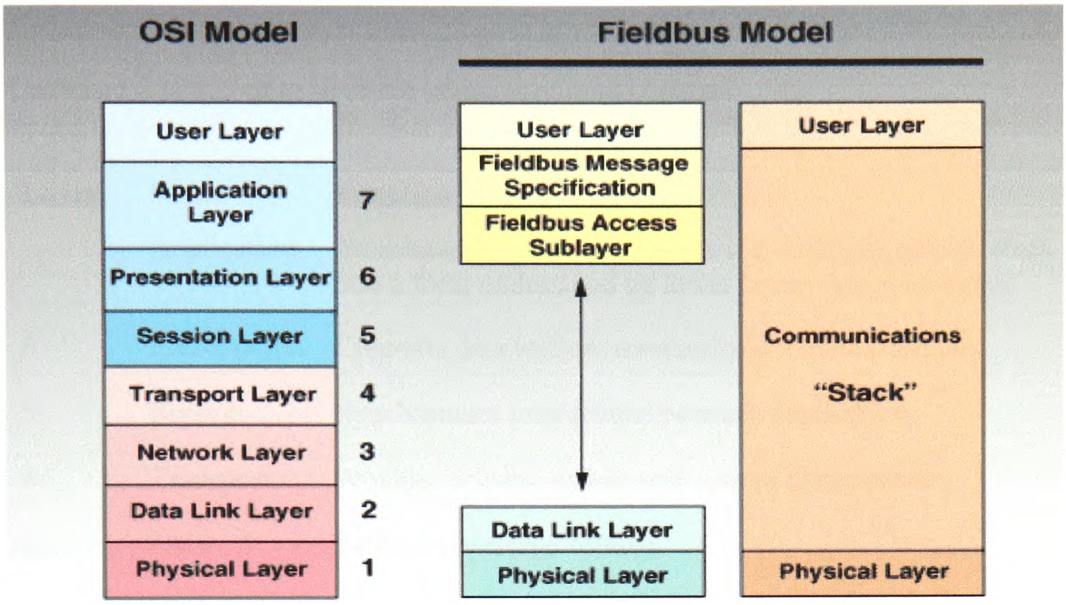


Figure 3-2[v] *The OSI/ Fieldbus Model*

Each layer provides services for the layer above it, and communicates with the corresponding layer in the stack of the other station[vi]- its *peer,* (called *peer-to-peer communications*). The set of facilities a layer provides to the above layer is called *services*.

When transmitting data from one application to another the data is passed down through the layers, before being passed over the medium, each layer adding header and, in the case of the Data Link and Physical Layers, trailer bits. The transmitting data having passed through all the layers now resides in the physical layer as a complete 'transmittable data frame'. The completed frame is then transferred through

[v] Source: Fieldbus Foundation Journal Feb 1997, http://Honeywell.com/Pub/Journal, 21st Feb 2001.

[vi] Station is the equivalent to a Node or device

the transmission media to its peer. The data frame is reduced to user data by performing the reverse operation of successively stripping header and trailer bits when a received frame progresses from layer 1 to 7.

The basic function of each of the layers is outlined below.

Layer	Name	Function
7	Application	Translates demands placed on the communications stack into a form understood by lower layers, and vice-versa
6	Presentation	Converts data to/from standardized network formats
5	Session	Synchronizes interactions between applications
4	Transport	Provides reliable end-to-end system data transfer
3	Network	Performs message routing
2	Data Link	Constructs data frames and detects errors in them
1	Physical	Electrically encodes/decodes data and transfers data over physical link.

Although there are seven layers, many fieldbus protocols use only three (the Physical, Data Link and Application Layers). This simplification makes fieldbus faster- in terms of protocol encoding efficiency and easier to implement. The partitioning of layers is possible, as most industrial applications require only communications between devices, thus requiring less functionality than would be required to interconnect between networks. An example of this is the CAN (Controller Area Network) Kingdom protocol using layers 1, 2 and 7 only. In the following sections the functionality of these sub set of layers are discussed in more detail.

3.2.2 Physical Layer

The physical layer specifies the media for transmitting/receiving data in terms of communication rates, signal encoding, length of connections, power supply on the bus. Although the physical layer describes the connection to the communications medium, it does not dictate the actual form of the transmission medium, nor its specific performance characteristics.

3.2.3 Data Link Layer

The data link layer has four main purposes:

Error Detection- deals with any errors produced when transmitting over the physical media, and thus minimizes the number of errors passed onto the higher layers. Techniques such as Cyclic Redundancy Check (CRC) can be employed (see section 3.6 for further detail on this and other techniques).

Flow control- this is used to cope with the problems inherent when a fast sender passes messages to a slow receiver. One solution is to prevent the source from transmitting until it receives an explicit acknowledgement packet (ACK) from the destination. The ACK indicates that the previous packet has been received and processed.

Link Management- this deals with the rules that both sender and receiver must follow in order to exchange information. For example, a sender and receiver may need to identify themselves to each other and be willing and ready to communicate before exchanging information.

Medium Access control- controls access to the transmission medium itself. Its purpose is to cope with the problem of two or more Nodes sending data simultaneously: either by preventing the problem from happening, or by recognizing a 'data collision' (Two devices (stations), trying to send messages on the transmission medium at the same time), and resolving the problem so that data and messages are not lost.

3.2.4 Application Layer

The Application Layer is the layer that the user program and processes access to communicate over the network. The Application layer is responsible for:

- Providing complete addresses for 'named' remote application processes
- Control of security
- Checking the authenticity and authority of the communications link end systems
- Error control and recovery

The Application Layer makes use of services provided by all the lower layers [Farsi and Barbosa, 2000].

3.3 DATA COMMUNICATIONS

This section discusses the basic principles of data communication with relevance to industrial networks.

3.3.1 Serial Communication

Fieldbus networks work on the basis of serial communication (Figure 3-3), where the data bits are sent sequentially over the Bus, as opposed to parallel communications where all data bits are sent at the same time, each bit travelling through individual conductors. Parallel transmission (Figure 3-4) is via a multi-conductor cable and can only, for practical and economic reasons, be carried out over short distances. For this reason most external data communications are achieved using serial communications.

The disadvantages of serial communications are the higher demands placed on the receiver and the transmitter which have to keep track of when a message starts and ends and the inherent sequence of bits. The transmitter and receiver must transmit and receive at the same rate. This property is known as the transmission rate and is expressed in bps (bits per second).

In order for the receiver to detect frame start and end, the transmitter sends out extra bits- a start bit and one or several stop bits.

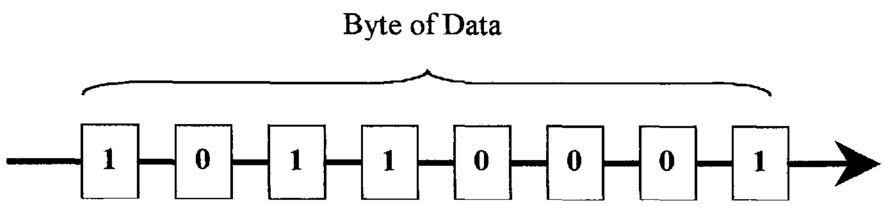


Figure 3-3 *Serial Communications*

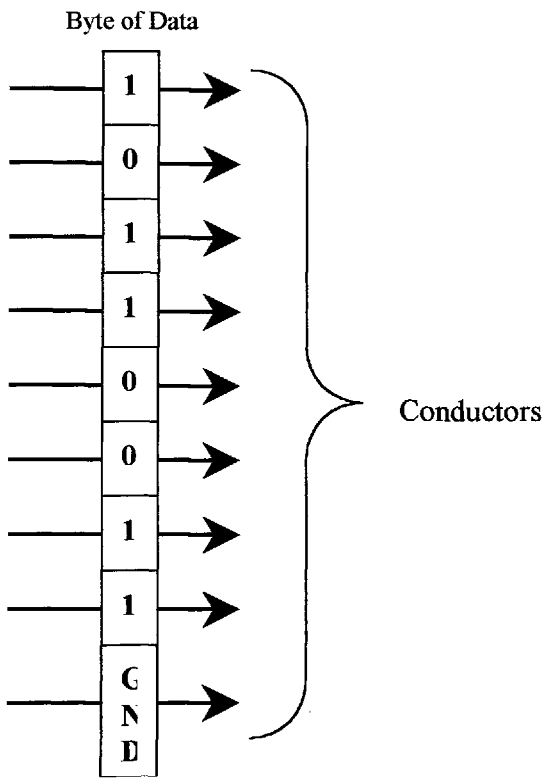


Figure 3-4 *Parallel Communications*

3.3.2 Data Synchronization

There are two methods of serial transmission known as asynchronous transmission and synchronous transmission [Quinn, 1995].

In asynchronous transmission both the transmitter and receiver are independent, each with their own clock running at the same frequency. Generally, the start of the transmission synchronizes the clock at the receiver end with that of the transmitter and from this point on both clocks run asynchronously from one another. Around 90 – 95% of serial data transmission is asynchronous [Westermo, 2001].

In the synchronous method the entire message is sent in an even flow. The rate is maintained by a clock signal on a separate wire or modulated on the data signal

The advantage of asynchronous transmission is that it is simple and inexpensive. The disadvantage is that it is inefficient in comparison with synchronous transmission since as much as 20 –25% of message content comprises of parity bits.

3.3.3 Transmission Speeds

The maximum rate at which data can be transferred from the source to the receiver on a communications interface depends on a number of factors:

- Type and complexity of the circuitry at each end (Interface)
- Communication medium (twisted pair, coaxial cable, fiber optic etc.)
- Distance between sender and receiver
- Amount of data being transferred
- The overhead associated with the data transfer
- The acceptable rate of error

The lower the data rate, the less complex are the requirements of the communication medium, the source and receiver circuitry and the fewer the errors due to timing and noise problems.

As previously mentioned the data transfer rates are measured in bits per second. This gives an indication of the amount of user data that has been transmitted, excluding the overhead bits. For example if ten bits are required to transmit one character at a transmission speed of 9600 bps, then 960 characters per second are transmitted.

The Baud Rate[vii] is considered to be the physical rate, or signaling speed, at which bits can be transmitted and correctly received on the communications interface. For example, if each bit occupied a time of 1 millisecond (ms), the Baud Rate would be 1000 Baud; which is the signaling speed.

Baud Rates are usually quoted in standard values of 50, 110, 300, 1200, 2400, 4800, 9600, 19200, 38400, 57600, and 115200 Baud and higher.

It is common practice in industry to use the term Baud Rate and data transfer rate interchangeably, unless it is specifically noted that they are not equal.

3.3.4 Data Transmission Techniques

The normal way to transmit information through a medium is to vary an electrical signal at the transmitting end and detect these variations at the receiver. There are two factor's - attenuation and noise, which can influence the successful reception of the signal. Noise can emanate from a variety of sources in the environment and serves to distort the signal. Attenuation is a measure of how much the strength of the signal is reduced in passing through the medium. It is proportional to the distance traveled and

[vii] named in recognition of Maurice Emile Baudot

will be present to differing degrees depending on the frequency of the signal being transmitted.

For a particular medium, there will be a range of frequencies that can be transmitted through it without incurring significant attenuation. This is known as the 'bandwidth' of the medium.

Given that the transmission has a particular bandwidth, there are a variety of ways of transmitting information through it. For instance, in fieldbus networks, there are two types of transmission commonly used - baseband and broadband transmission. The details of these two methods are discussed in the following sections.

3.3.4.1 Baseband Transmission

The simplest form of transmitting digital information is to have two voltage levels to represent 1s and 0s. More sophisticated schemes such as Manchester Encoding can be used.

In baseband transmission the voltage encoded signal is applied directly to the medium. The signal is attenuated in its passage through the medium causing the quality of the received signal to decrease with distance traveled. Two-way transmission is possible.

3.3.4.2 Broadband Transmission

A signal that has been modulated will have a fixed bandwidth requirement, which is often considerably less than is provided by the medium in use. In order to make more use of the cable, it is possible to divide its bandwidth up into channels, each of a predefined bandwidth [Squibb, 1985].

One way direction of transmission is permitted per carrier frequency; therefore if Nodes are to send as well as receive on a single carrier a ring concept is needed (see Section 3-5 for further details on topologies).

The cost to transmit and receive using this method is more expensive than any other type as it requires a device to carry out transmission and reception called a modulator/demodulator often abbreviated to MODEM. This is one of the reasons why broadband is perceived as being unsuitable for most device level applications, baseband being far more commonly used.

3.4 INTERFACING

Whilst interfacing **does not define a protocol** it does define the electrical and mechanical details of an interface. The Electronic Industrial Association (EIA) has over the years produced several serial data interfaces, the best known being EIA-RS[viii]-232-C[ix] simply referred to as RS-232C. The structure of RS-232C, which is designed for one to one communication over short distances, is not appropriate for a multi-drop system required by a fieldbus system. The most frequently used interface standard for fieldbus systems is RS-485.

3.4.1 EIA RS-485

The RS-485 is an updated version of RS-422. It is designed for balanced, multi-drop communications, with up to 32 devices on the same transmission medium and is recommended for distances up to 1200 metres at data rates up to 10 Mbps.

[viii] RS is an acronym for Recommended standard

[ix] 'C' indicates this is the third revision

One of the advantages of using this interface is that it can reverse the direction of communications, allowing for half duplex transmission on two-wire lines. This is the transmission method for many popular fieldbus standards, for instance, Profibus, Bitbus and Interbus-S.

The line voltage ranges between –1.5V to –6V for logic '1' and +1.5V to +6V for Logic '0'. The line driver for the RS-485 interface produces a 5V differential voltage on two wires. Full duplex systems require five wires whilst for half-duplex system only three wires are required.

A major advantage of RS-485 is that a line driver can operate in three states (called tri-state operation), logic '0', logic '1' and high impedance. In high impedance state the line driver draws virtually no current and appears to be disconnected from the line. A control pin on the line driver integrated circuit can initiate the 'disabled' state. This feature allows 'multi-drop operation', although only one line driver can be active at any one time. For these reasons each device must be allocated a unique address to avoid any conflict with other devices on the system. [IDC, 1994]

3.5 TOPOLOGY

Topology describes how the communication media interconnects the Nodes. The type of topology chosen will govern the flexibility of the bus and the performance. Unfortunately, there tends to be an inverse relationship, the more free form the topology is, the lower the performance [Svacina, 1998].

There are several topologies in use the four most common being:

1) Star
2) Ring (loop)
3) Bus (often referred as Linear trunk, or Multi drop)
4) Tree

1) **Star** (Figure 3-5) -is an arrangement whereby each Node is connected individually through a single path to a central Node, often referred to as the hub. This topology is primarily used for telephone systems and wide area networks (WAN's).

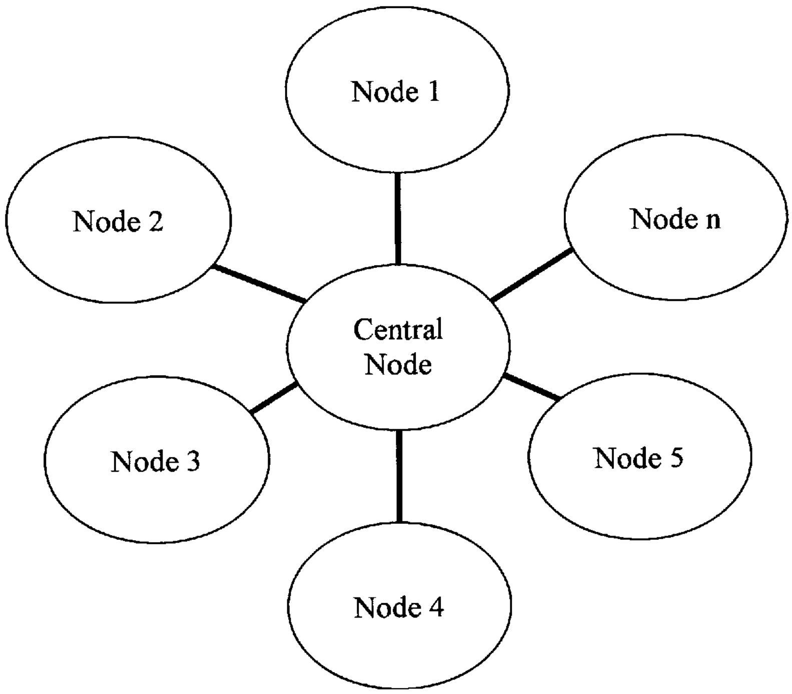


Figure 3-5 *Star Topology*

The main advantages of star networks are:

- Ease of service- the star topology has a point of concentration i.e. a central Node which provides easy access for service or reconfiguration of the network.

- One device per connection- this structure allows for the addition of further Nodes, without interrupting the network. The function of the network is not jeopardized by the failure of a single Node.

- Simple access protocols- as any given connection in a star network involves only the central Node and one peripheral Node, contention for who controls the medium with regard to transmission purposes is easily solved via a simple protocol.

Disadvantages of the star topology:

- Long cable lengths- as each Node is directly connected to the central Node, the star topology requires large quantities of cable, which results in increased costs, maintenance and installation problems.

- Central Node dependency- if the central Node fails the entire network fails.

2) **Ring**-is structured in such a way that each Node is connected to two and only two neighbouring Nodes. On a true ring, every Node is also a repeater. The data passes into a Node, information pertaining to that Node is then read, new information is added and the message is sent onto the next Node (Figure 3-6).

Advantages of a Ring:

- Distance- the signal is refreshed at each Node, hence greater distances can be covered.

- Optical fibers-the unidirectional flow is ideal for optical fibers since every network segment looks like a point to point connection in one single direction. As such a considerable saving in wiring results.

Disadvantages of a Ring:

- It is impossible to extend the net while it is running, as that would break the ring. Similarly, if one Node stops working, or one segment breaks down, the whole network stops running.

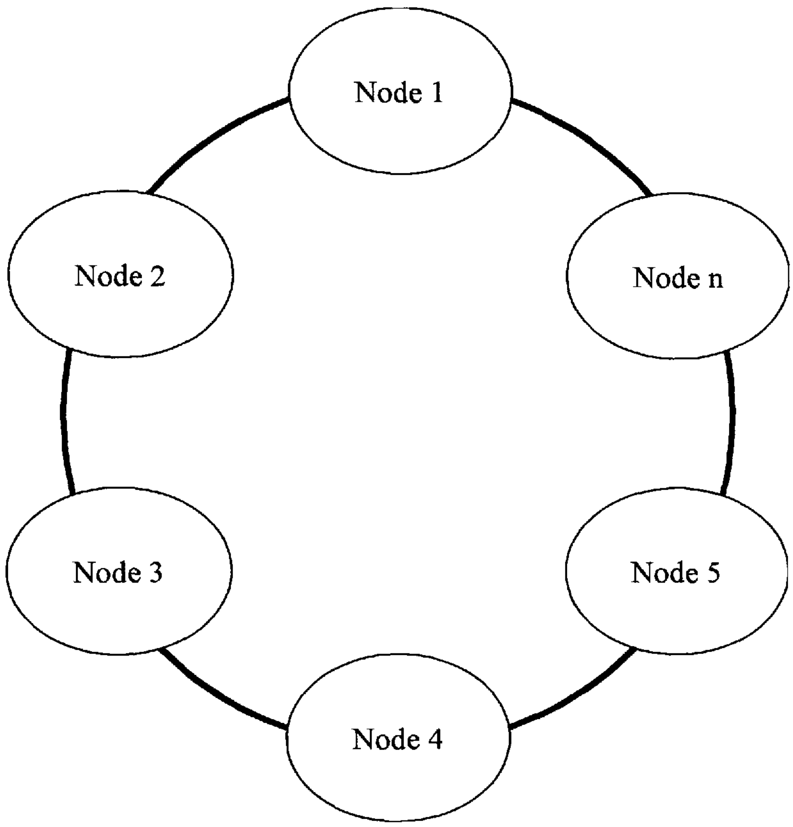


Figure 3-6 *Ring Topology*

3) **Bus topology** - this consists of a single length of transmission medium onto which the various Nodes are attached (Figure 3-7). This configuration is also referred to as a 'multi drop line'.

Advantages of the Bus Topology:

- Simple wiring layout and short cable lengths- as there is a single common data path connecting all Nodes, the Bus topology allows a very short cable length to be used. This decreases the installation cost and also leads to a simple, easy to maintain layout.

- Resilient architecture-the BUS architecture has an inherent simplicity making it very reliable from a hardware point of view. There is a single cable through which all data propagates and to which all Nodes are connected.

- Easy to extend- additional Nodes can be connected to an existing bus network at any point along its length. Greater distances can be achieved by the use of signal amplifiers known as *repeaters.*

Disadvantages of the Bus topology:

- Whilst a fault on one Node is unlikely to stop the network from running (unless in exceptional circumstances whereby the node introduces a short circuit across the bus). A fault in the network medium itself causes an entire segment of the bus to be disconnected.

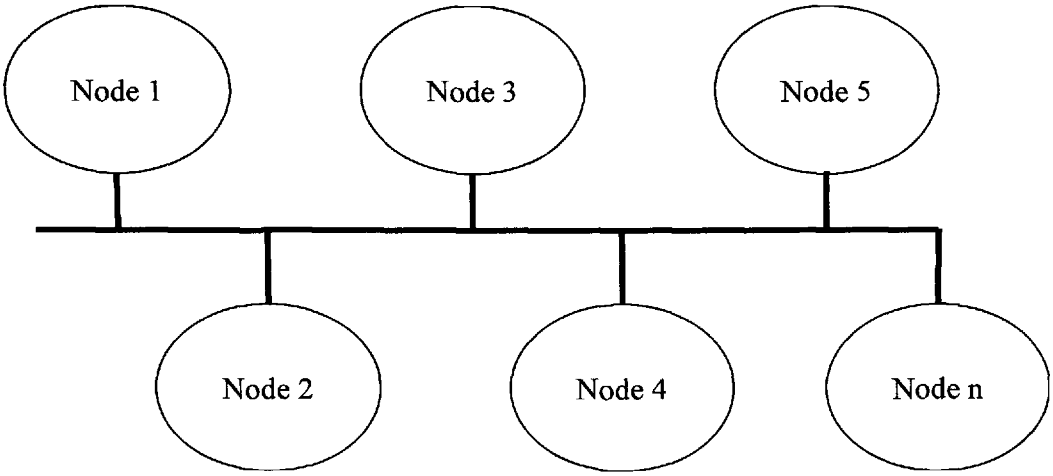


Figure 3-7 *Bus Topology*

Tree- the Tree topology (Figure 3-8) is a variant of the Bus topology it is the most popular topology for fieldbuses. Its advantages and disadvantages are similar to those of the ring and star topologies.

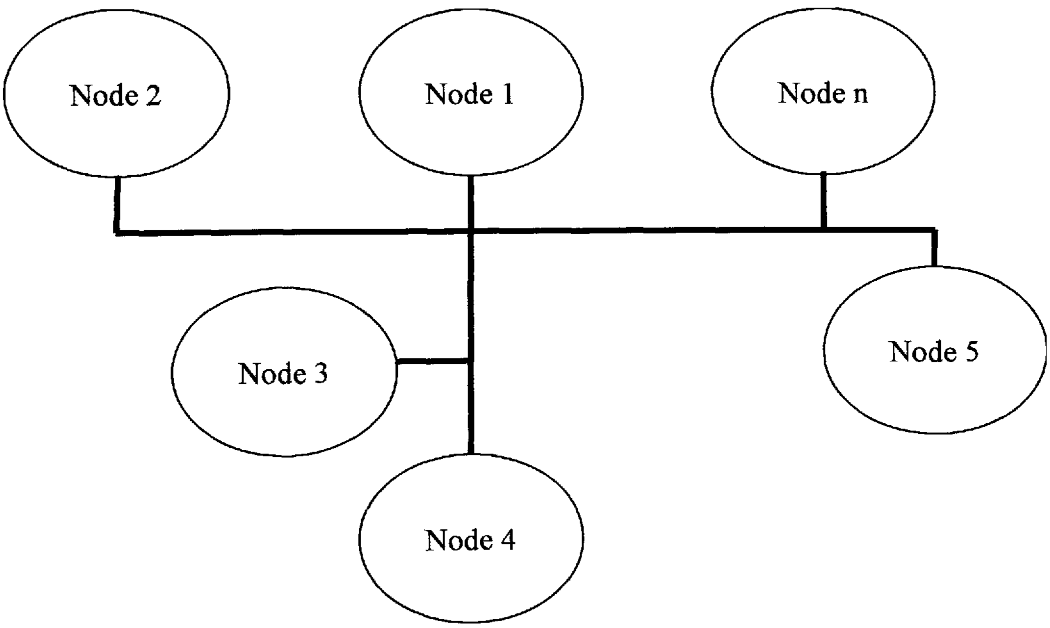


Figure 3-8 *Tree Topology*

As discussed earlier in this section it is often possible/necessary to extend a network using a repeater (Figure 3-9).

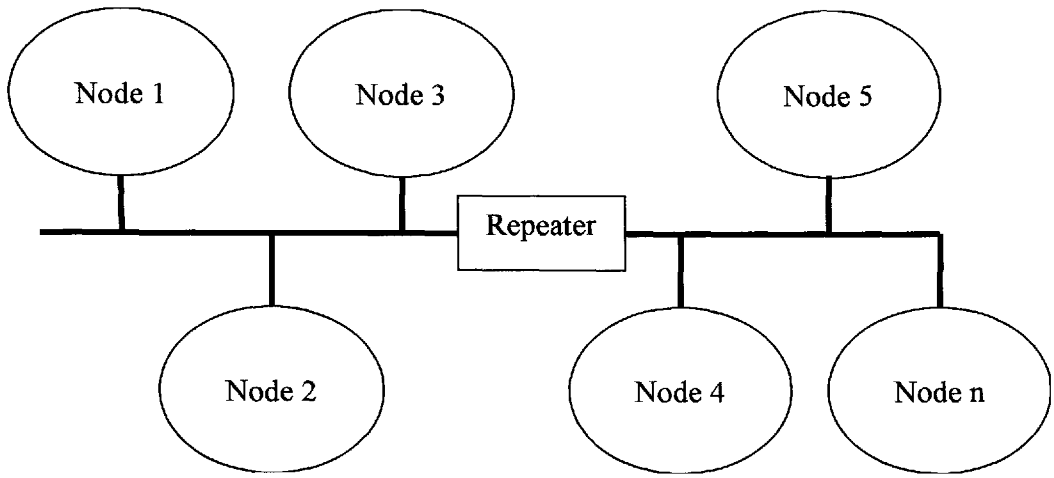


Figure 3-9 *Repeater*

A repeater, or amplifier as it is also known, is a device that enhances and re-shapes electrical signals, allowing an extension of the network and a larger number of Nodes to be connected to the network.

Other devices, such as bridges/gateways, are used to connect differing sections or buses with different coding and electrical characteristics.

3.6 MEDIUM ACCESS CONTROL METHODS

In the previous section, it was seen that in all network topologies, except the star, the medium was shared between a number of Nodes. In Bus and Ring, all Nodes are connected directly to the common medium.

This common access to the medium raises the problem of how to ensure one Node's transmission does not interfere with another. To avoid collisions a means of sharing access must be provided.

To overcome this problem many different methods for medium access control (MAC) have been developed. Some of the more popular techniques are listed below:

- Single Master (Master/Slave)
- Carrier Sense Multiple Access with Collision Detect (CSMA/CD) = IEEE 802.3.
- Carrier Sense Multiple Access with Bit Arbitration (CSMA/BA)
- Token Ring = IEEE 802.5.
- Token Bus = IEEE 802.4

3.6.1 Single Master (Poll/select)

This MAC technique is based on one Master device controlling all transmissions. The other devices, referred to as Slave devices, in their simplest form may only communicate when permitted by the Master device. In a simple implementation, each device is polled in turn and each has a fixed reply message length. An error detection mechanism is inherent within this method of communication i.e. if after a certain predefined time-out period a Node failing to reply to a request it may be deemed to have failed. A simple Master approach is capable of precise cyclic updates of data.

This technique can also be used in a multi-Master mode. However, cyclic performance is impaired when in multi Master mode.[BSI, 2000]

3.6.2 CSMA/CD

The transmitting Node on a network using CSMA/CD will first check the bus is clear i.e. there are no electrical signals on the bus (Carrier Sense). If there are no other

Nodes transmitting, then the Node can begin the transmission of its frame. Other Nodes will acknowledge this transmission and as such will not attempt to transmit themselves, so avoiding any collisions.

However, it is possible that two or more Nodes will determine that the bus is idle. Both will begin to transmit simultaneously[x] and thus a collision will occur. If this situation arises, both Nodes will stop their transmissions. After a period of time, and provided the bus is free, the Nodes will try to transmit again. CSMA/CD is statistically based, with a probability of access that falls rapidly if the transmission load on the media increases above about 40% of bandwidth. Hence jitter[xi] is a function of total load [BSI, 2001].

3.6.3 CSMA/BA

This variation on CSMA provides collision avoidance using bit arbitration. With this technique the message from each device begins with its own unique address. In the event of a collision the device with the lowest address (hence the highest priority) is allowed to transmit.[Breeze, 1998, p19]

3.6.4 Token Passing

This technique employs a noncontentious method of access control. This method works by passing a unique transmission sequence called a *token* from one Node to another. When a Node has taken possession it has permission to transmit a packet of data, after which it must pass on to the next Node in sequence.

[x] The transmissions may not be required to be exactly simultaneous as prorogation delays will have an effect.

[xi] Variation in time between consecutive executions of cyclic events

3.6.4.1 Token ring

When the above method is used with the ring topology, a token is circulated around the ring, from each Node to Node in sequence. When a Node wants to transmit data, it seizes the token and then transmits the data. Incorporated in the data frame will be a destination address. The data frame will pass from Node to Node until the destination Node is reached. The destination Node first copies the contents of the frame and then acknowledges it has received the copy correctly by setting the appropriate bit. The data frame is then returned to the source address, which in turn removes the frame and passes on the token.

3.6.4.2 Token bus

Normal operation in a token passing bus is very similar to that of the token passing ring. The token constituting permission to transmit is circulated from one Node to another around the logical ring. Nodes using this access method must be ordered into a logical ring[xii] to enable the token to be passed sequentially through each Node.

3.7 ERROR DETECTING AND CHECKING MECHANISMS

All communication networks are prone to errors. For example, due to electrical noise data bits may get corrupted during transmission. Techniques have been developed to detect and in some cases recover such errors. Five of the most commonly used in fieldbus systems are discussed below.

3.7.1 Cyclic Redundancy Check (CRC)

This method is based on polynomial codes generated through the division of the frame contents. The same operation is carried out at the receiver end and the results

[xii] The logical ring need not in any way reflect their physical arrangement

compared. If a difference is detected then an error is deemed to have occurred. The mechanism is illustrated in the following:

- Take a MESSAGE and multiply by 2^{16}
- Divide (using modulo 2 arithmetic) by an arithmetic divisor (for example the CRC-CCITT[xiii] which is 1000 100 00001 00 001) to obtain a quotient and remainder. The remainder is the CRC checksum.
- Append the CRC checksum to the message
- The receiver carries out the same calculation and compares the result with the checksum received.

3.7.2 Complementary Data Retransmission (CDR)

Complementary data retransmission is a method of verifying that a received multi-bit signal value matches that transmitted by the signal's source device. This is accomplished by the source device sending an encoded version of the signal data along with normal signal data, and the receiving device comparing the two values. If the encoded value matches the original value then the data is accepted by the receiving device; otherwise the data is rejected.

3.7.3 Hamming Distance (HD)

Hamming distance is a measure of the difference between two messages, each consisting of a finite string of characters and expressed by the number of characters that need to be changed to obtain one from the other. For example, 0101 and 0110 has a hamming distance of two, whereas "butter" and "latter" are four characters apart. Thus the larger the hamming distance, the better the detection system.

[xiii] CCITT is an abbreviation for the Consultative Committee in International Telegraph and Telephone.

3.7.4 Data Echo Feature

Data echo provides a method for a signal-transmitting device to verify that a single bit data signal has been received correctly by another device. This feature provides both message acknowledgement and data verification.

In this method, a device that receives a single-bit data signal re-transmits that signal back to the bus. For instance, a discrete output device, such as a valve, could echo its control signal back on the bus as an input signal.

3.8 NODE ADDRESSING

In all networks where the transmission media is shared between Nodes in the network, each Node is normally assigned a network address. This address is what determines the destination for the data i.e. the Node intended to receive the information. In most networks the frame format will have both the source and destination addresses encoded in it. The general format of the frame is shown below (Figure 3-10).

Destination address	Source address	Data	Error Check

Figure 3-10 *Frame Format*

The source information allows the destination to determine where to send a response (if required). There are several addressing methods used in industry some of the important ones are discussed in the following sections

3.8.1 Master/Slave (one to one)

In this method (Figure 3-11) the source address is often omitted, as the response from any Node is always directed at the Master.

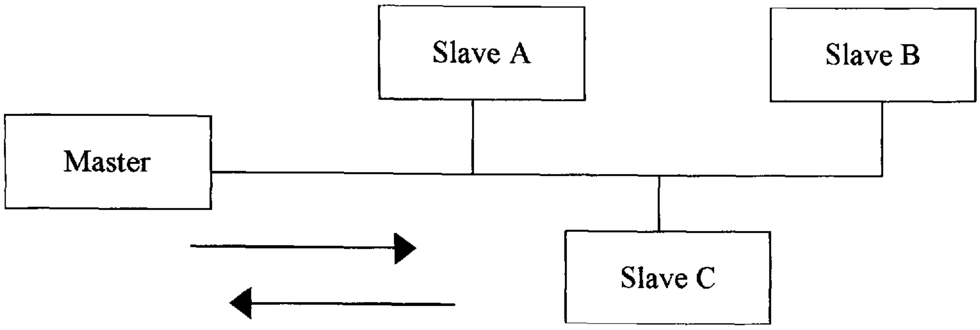


Figure 3-11[xiv] *Master/ Slave Transmission*

This type of system is inherently a one to one data exchange process i.e. there is no possibility of transmitting to several Nodes at the same time.

3.8.2 Peer to Peer (Slave to Slave)

In a Peer to Peer configuration (Figure 3-12) devices may communicate directly with one another whilst the source/destination address scheme allows the destination device to reply to the source device.

This type of network uses MAC methods, such as token passing techniques, to control which Node can gain access to the bus to thus initiate a request [Farsi & Barbosa. 2000].

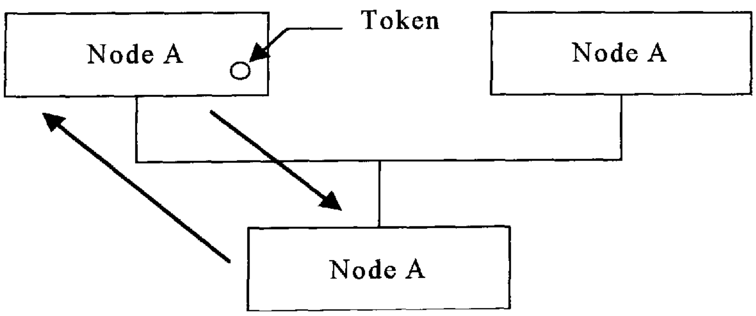


Figure 3-12 *Peer to Peer Transmission*

[xiv] Source: Farsi, M. CANopen Implementation: applications to industrial networks

3.8.3 Publisher- Subscriber (Producer/Consumer)

Publisher-Subscriber mode of operation applies the concept of group addressing to a connected service.

Each configured data source (publisher) takes accountability for publishing defined data in association with the unique connection identifier, without knowing the identity of the recipients (subscribers). Interested subscribers can obtain the connection details and use them to receive the data each time it is published. This method allows all subscribers to get the same data at the same time without wasting valuable communication bandwidth repeating the message to each recipient (Figure 3-13).

It is also possible to configure Nodes to receive more than one item of data i.e. several frames with different identifiers.

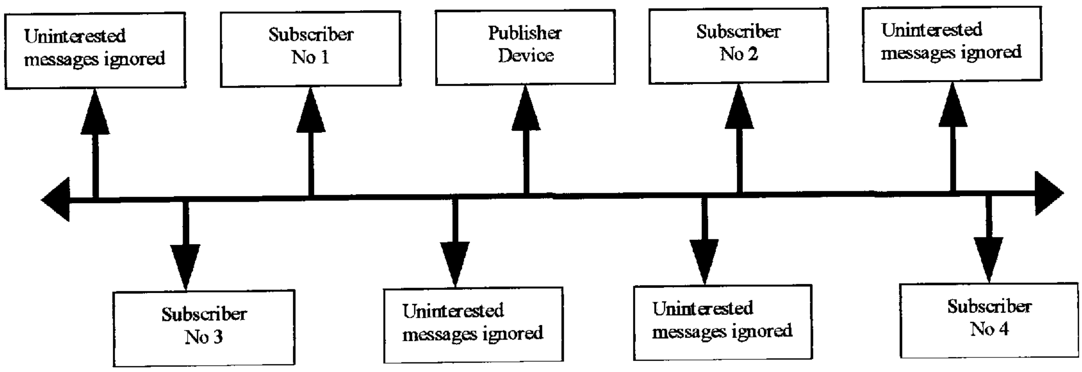


Figure 3-13[xv] *Publisher Subscriber Method of Operation*

3.9 INTERNATIONAL FIELDBUS STANDARDS

The definition of "open"[xvi], as previously explained in Chapter 1, introduces the concept of interoperability. Interoperability means that a component from one vendor

[xv] Source: BSI guide to the evaluation of fieldbus protocols- selecting the best fieldbus for your application

can replace a similar component from another without complication or loss of production.

Table 3-1

Major Stages in the Development of an International Fieldbus 1984-2000

Date	Event
1984	ISA announces a project to develop a fieldbus specification by 1989
1984	First P-Net products developed in Denmark.
1986	Eureka Project developed to develop a common European fieldbus.
1987	Club FIP is founded by Cegelec, Telemanecanique and EdF
1989	P-Net is adopted as the open standard in Denmark.
1990	IFG founded by Siemens, Rosemount, Endress & Hauser and others.
1990	OFC, a rival organisation, founded by Honeywell, Allen Bradley & Foxboro
1990	International Fieldbus Consortium formed from IFG/OFC merger
1990	Profibus adopted as national standard in Germany
1991	IEC Committee draft for parts 3-6
1992	International Fieldbus Network formed to break the logjam.
1993	ClubFIP extended to Asia and North America to form World FIP
1993	IEC Publish Part two of 61158
1994	ISP and WorldFIP North America merge to form Fieldbus Foundation
1994	IFC dissolves itself
1996	EN50170 is adopted as European standard
1996	The Foundation begins NOAH project to make the three European standards compatible.
1998	IEC vote ends in confusion.
2000	IEC publishes 61158-3, 61158-4 containing an additional seven protocols.

[xvi] Another interpretation by the IEEE has defined an open system in the following way:

An open system provides capabilities that enable properly implemented applications to run on a variety of platforms from multiple vendors, to interoperate with other applications and to present a consistent style of interaction with the user [Steinhoff, 1998].

To accomplish this requires the development of, and adherence to, Industry standards. Due to the time taken to agree a single industrial fieldbus standard (IEC 61158), (Table 3-1) the European Committee for Electrical Standardization (CENELEC) has published its own European industrial fieldbus standards. The following section will discuss further the role of the two Commissions and other bodies involved in the fixing of standards for fieldbus systems.

3.9.1 International Electrotechnical Commission

International standards began in the Electro technical field: the IEC was created in 1906, and has the following mission:

"To promote, through its members, international co-operation on all questions of standardization and related matters, such as the assessment of conformity to standards, in the fields of electricity, electronics and related technologies" [IEC].

The membership consists of more than 50 participating countries, including all the worlds major trading nations and a growing number of industrializing countries. Adoption of IEC standards by any country, whether it is a member of the Commission or not, is purely voluntary.

A committee for the introduction of a *Fieldbus standard for use in industrial control systems* IEC 61158 was formed some 15 years ago. IEC 61158 is split into seven parts these being;

Part 1: introduction

Part 2: physical layer specification and services definition[xvii]

Part 3: data link layer service definition

[xvii] Also published by British standards Institute as BS EN 61158-2

Part 4: data link layer protocol specification

Part 5: application layer service definition

Part 6: application layer protocol specification

Part 7: System management

Part 2 was first published in 1996, with the second edition published in year 2000. Parts 3-6 containing the new eight-part protocol previously discussed in Chapter 1 was published in year 2000. Parts 1 (Introduction) and 7 (Management) are still to be completed and as such have not been published.

Other notable IEC standards are:

IEC 62026[xviii]: Controller- device interfaces for low voltage switchgear and controlgear contains 3 controller device interfaces: AS-I, DeviceNet, and SDS.

3.9.2 ISO

The ISO was formed in 1947. The ISO is a worldwide federation of national standards bodies from some 130 countries and, with the exception of electrical and electronic engineering, deals with all technical fields. Work in the field of information technology is carried out by a joint ISO/IEC technical committee [ISO].

The ISO have produced a number of fieldbus and control systems standards. These have been developed for specific products and have been adopted for use in industrial applications, for instance:

[xviii] IEC62026-2 is technically equivalent to EN50295, and parts 3 and 5 of IEC 62026 are technically equivalent to parts 2 and 3 of BS EN 50325 respectively.

- BS ISO/IEC 7498-1[xix]: 1995 Information technology – open systems interconnection – basic reference model: Part 1 The Basic model

- ISO 11898 adopted by CAN : 1993 road vehicles- interchange of digital information- Controller area network (CAN) for high speed communications

CAN is now used by open fieldbus systems such as DeviceNet and Seriplex.

3.9.3 CENELEC

CENELEC was set up in 1973 as a non profit making organization under Belgian law.

It has been officially recognized as the European Standards Organization in its field by the European Commission in Directive 83/189/EEC.

CENELEC and IEC, the two most important standardization bodies in the Electrotechnical, field have an agreement for full cooperation. This agreement, is known as "The Dresden Agreement." It was approved and signed by both parties in Dresden in September 1996 [CENELEC]. This agreement (which relates to common planning of new work and parallel CENELEC/IEC voting) intends:

- To expedite the publication and common adoption of International Standards.

- To ensure rational use of available resources. Full technical consideration of the content of the standard preferably take place at international level.

- To accelerate the standards preparation process in response to market demands

[xix] As previously discussed this is reference model only and not a standard

It can be seen from the discussions on the IEC that there is a clear relationship between standards published by the IEC and CENELEC. Other relevant standards produced by CENELEC are:

- EN 50170: 1997 General purpose field communication systems
- EN 50254: 1999 High efficiency communication subsystem for small data packages.

3.10 SUMMARY

A fieldbus system in its simplest form operates with data being passed bi-directionally between two devices sharing the same medium.

In order for the system to operate, all devices on the system must obey a set of rules known as a protocol. The ISO/OSI reference model consisting of seven layers known as a stack was devised and released in 1978. This chapter has concentrated on the three layers that are generally used for device level fieldbuses, these being the physical, data link and application layers. The physical layer defines the physical characteristics of the transmission medium used. Its specifications include a description of the topology and transmission technique. The data link layer defines a link between Nodes. Error detection is also a part of the data link specification. The application layer is concerned with the application using the communication service. It can also define an interface through which a user program accesses the services.

Fieldbus systems work on the basis of serial transmission whereby data is sent sequentially one bit at a time, thus requiring only two conductors. There are two methods of serial transmission, asynchronous and synchronous. In asynchronous transmission both transmitter and receiver have their own clocks running at the same frequency. Synchronous method can be achieved in several ways, either by a clock signal on a separate wire or modulation on the data signal.

Transmission speeds are dependent on a number of factors, for example, the type of communication medium used, distance and amount of data being transferred. The data rate is measured in bits per second. The other measurement of transmission speed is known as the Baud Rate. This is considered to be the physical rate, or signaling speed.

There are two types of transmission techniques used in fieldbus networks-baseband and broadband. In baseband transmission, a voltage encoded signal is applied directly to the medium. In broadband transmission, a modulated signal is applied to a carrier wave. The cost to transmit and receive is more expensive than baseband as devices require both a modulator and demodulator and as such this method is less popular in device level fieldbus systems.

The interface between devices, as defined by the EIA, sets out the electrical and mechanical details of an interface but does not define the protocol. The most widely used for fieldbus networks is the RS-485. RS-485 is designed for balanced, multi-drop communications, with up to 32 devices on the same medium. It is recommended for distances up to 1200 meters at data rates up to 10Mbps.

Topology describes how data lines connect the Nodes together. There are several commonly used topologies; Star, Ring, Bus, Tree. A Star network has a central Node whereby each Node is connected directly to it through a single path. The Ring topology, as its name implies, connects one Node through the next in series to form a ring. The Bus structure consists of a single length of transmission medium onto which the various Nodes are attached. This structure is often referred to as a multi drop line.

The tree topology is a variant of the bus topology in which multiple branches and sub branches are allowed.

In all except the Star structure the medium is shared between a number of Nodes. To allow access to the medium, without transmissions interfering or colliding with each other, two types of techniques are used-contentious and noncontenious. Non contentious avoids collisions, where as contentious allows for collisions but incorporates a technique for recovery.

Due to factors such as electrical noise, all communications are prone to errors. There are several techniques for detecting errors. The most common techniques used in device fieldbus systems are; CRC, CDR, HD, Data Echo.

Fieldbus systems may communicate with other Nodes in several ways i.e. Master/Slave, Peer to Peer or Publisher Subscriber. The Master Slave as it implies means that all Nodes talk to each other via the Master. Peer to peer operates by each Node communicating directly with the specified Node and vice-versa. This is sometimes referred to as a Slave to Slave configuration. Publisher subscriber allows for group addressing of Nodes.

To ensure reliable and coherent communications between devices sharing a medium both the protocol and the interfacing have been defined in various national and international standards.

The next chapter discusses in detail the features of the fieldbuses used in the selection process.

CHAPTER 4

FIELDBUS SELECTION

This Chapter deals with the selection of the optimum fieldbus for use within the paper converting process. As a result of the myriad of detail and criteria involved in selecting a fieldbus, it was decided to evaluate two methodologies

1. Professor Gerhard Gruhler's Procedure
2. Kepner Tregoe Decision Analysis

Professor Gerhard Gruhler's procedure was developed in association with other members of the ASPIC Consortium (ASPIC Project, 1992- 1995) [Gruhler, 1993]. Figure 4-1 shows the general procedure for selecting a network or bus system.

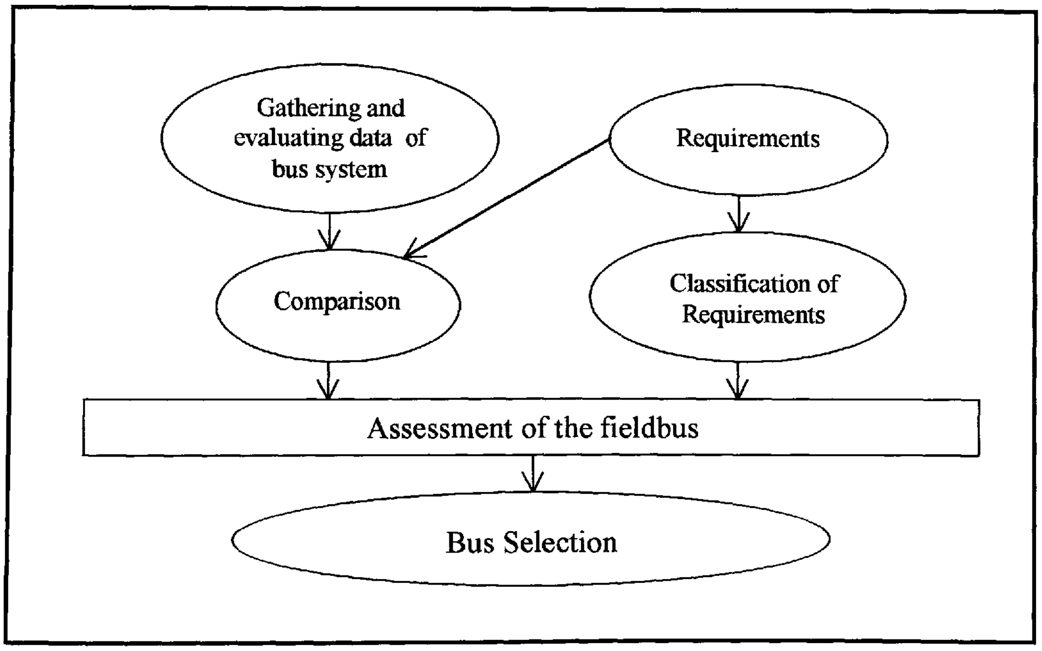


Figure 4-1 *Prof G. Gruhler's Procedure for Selecting a Network or Bus System*

There are two major drawbacks with Professor G.Gruhler's decision analysis. These are;

- It does not provide a method of evaluating potential risks associated with the fieldbus selection, and as such would not have the capacity to detect adverse consequences that could influence the final selection of a fieldbus.
- It does not provide any in-depth guidance notes. This omission makes it very difficult to implement the methodology and indeed could leave it open to incorrect implementation resulting in a possible wrong selection.

For these reasons it was decided to reject Professor Gruhlers method in favour of Kepner Tregoe

Kepner Tregoe decision analysis was developed by Dr C.H.Kepner and Dr B.B.Tregoe in 1965, and is now used in organizations such as N.A.S.A, Sony and Bosch. It implements a systematic, informed, balanced and non-biased, two-dimensional approach to decision making.

The Kepner Tregoe's method was adopted as it is seen as one of the better known 'rational' decision making approaches within industry [Barker, 2000] and also as a result of its proven track record, thorough set of guidance notes, and the author's familiarity and successful previous implementation of the technique.

4.1 KEPNER TREGOES'S PRINCIPLES OF DECISION ANALYSIS

Set out below are the basic principles of Kepner Tregoe decision analysis. As this forms such an integral part of this research a copy of the manual is included in appendix A.

A thorough knowledge of both the converting process and fieldbus is an essential pre-requisite to carrying out Kepner Tregoe decision analysis, which is broken down into four main areas:

1. Identifying the goal.
2. Developing specific criteria for its accomplishment.
3. Evaluating the available alternatives relative to those criteria.
4. Identifying the risks involved.

4.2 TECHNIQUES OF DECISION ANALYSIS

The technique of decision analysis comprises of five elements:

1. The Decision Statement
2. Setting Objectives (Criteria)
3. Evaluating Alternatives
4. Assess Risks
5. Make Decision

The statement clarifies the fundamental purpose of the decision. For example, the statement "choose the location of the new Branch office" [i] makes the fundamental purpose of the decision clear. The decision statement introduces boundaries on the kinds of alternatives to be considered.

The decision statement also sets the generality and level of decision as well as the breadth of alternatives to be considered. A decision statement such as "Select a contractor for project A" indicates a decision has been made to exclusively use contractors. Raising the level of the decision statement to " Select the best way to

[i] All quotes and Tables 4-1 to 4-3 are extracts from the Kepner Tregoe manual included in Appendix A.

complete project A" broadens the scope of the decision and alternatives i.e. contractors are now only one of several options.

The next step after clarifying the fundamental purpose of the decision, is the setting of objectives that will best meet the decision statement criteria.

The list of criteria is a measuring stick by which to judge the various alternatives.

The objectives are split into two categories: MUSTS and WANTS. MUSTS are mandatory and measurable objectives, which have to be met or exceeded for the decision to succeed. WANTS are objectives that are desirable but not essential to the success of the decision. A degree of bias is attached to the WANT objectives in order to reflect their relative importance. Based on the classification of application requirements a weighting factor is assigned to each criterion on a scale of 10 to 1. The WANT objective with the highest degree of importance is designated a 10. The other WANT objectives are assessed relative to that benchmark[ii].

The first part in the evaluation process is to select a balanced set of alternatives.[iii]. These alternatives are then evaluated against the MUST objectives. Those alternatives, which do not meet any of the MUST objectives, are eliminated from further consideration.

Table 4-1 illustrates alternatives evaluated against MUST objectives.

[ii] Too many high numbers may indicate either unrealistic expectations or a flawed perception of which objectives can guarantee success.

[iii] Kepner Tregoe acknowledges that, in some situations, such as in the case of this research, suitable alternatives are generated prior to the decision analysis taking place.

Table 4-1 *Alternatives Evaluated against MUST Objectives*

MUST Objectives	Company A Info	GO/ NO GO	Company B Info	GO/ NO GO	Company C Info	GO/ NO GO
EEO Reporting	Yes – Meets Government Requirements	GO	Yes – Meets Government Requirements	GO	Yes – Meets Government Requirements	GO
Report Writing	Yes - all reports are printed using report writer.	GO	Standard reports use report writer on call.	GO	No- Report writer	NO GO
Capture/report salary and job History	Yes – using CEH	GO	Yes – can generate as many as wanted into system	GO	--------------	-------

The remaining alternatives will be evaluated against all the WANT objectives and relative to each other. A score of 10 is placed against the objective that is best aligned with the WANT objective, with all the alternatives being scored relative to that benchmark. Table 4-2 shows a simplified example of alternatives evaluated against WANT objectives.

Table 4-2 *Alternatives Evaluated against WANT Objectives*

WANT Objectives	Weight	Company A Info	Score	Company B Info	Score
Implementation within 6 months after start	10	Yes – 4 months	10	No – 6 Months	9
Written in Cobol	9	Yes – with called sub routine	9	Yes – no called sub routine	10
Elimination of multiple forms by using turnaround document	8	Yes – minimum number of forms & cust. Des documents	10	Yes – Minimum number of forms & standard document	9

A comparative measurement of the alternatives is achieved by multiplying all the weighted scores of the objectives by the WANT objective score of the alternative. An accumulation of all WANT objectives weightings give the total weighted score. The same calculation is performed on all the alternatives. The alternative with the highest score becomes the tentative choice[iv]. Table 4-3 shows an example of the alternatives and their weighted scores.

Table 4-3 *Alternatives and their Total Weighted Scores*

WANT Objectives	Wt	Company A Info	Score	Wt Score	Company B Info	Score	Wt Score
Implementation 6 months after start	10	Yes – 4 months	10	100	No – 6 Months	9	90
Written in Cobol	9	Yes – with called sub routine	9	81	Yes – no called sub routine	10	90
Elimination of multiple forms by using turnaround document	8	Yes – minimum number of forms & cust. Des documents	10	80	Yes – Minimum` number of forms & standard document	9	72
Total Weighted Score				261			252

The final stage in the decision analysis process is to consider the potential risks associated with the chosen alternative[v].

Guidance in ascertaining potential risks is as follows:

1. Deliberate possible failure if the alternative were to be implemented
2. Use data collected when comparing alternatives to provide future risks
3. Draw upon the experience of others i.e. case studies, interviews etc

Having identified the specific risks, an assessment is then made of their potential impact on the success of the decision. Judgement of the risk is examined by looking at two aspects of the threat it poses i.e. the probability that the risk identified will occur and the seriousness of the effects should it occur. The seriousness and probability are

[iv] It does not become the final choice until all potential risks are explored.

[v] This may not always be the case; if there are several alternatives with similar weighting then the process should be carried out on all the remaining alternatives.

weighted to give an overall assessment of the severity of the risk. Alternatives assessed as having potential risks with highly probable and highly serious consequences may be disregarded.

The ultimate step in the decision making process is to balance all the relative benefits and risks prior to committing to an alternative.

4.3 THE DECISION STATEMENT

The decision statement is:

"To select an optimum device level fieldbus for machine control within the paper converting industry".

The boundaries and level of the decision statement are derived from a study of the paper converting process and existing network characteristics of the Fort James plant in South Wales[vi].

4.4 MUST OBJECTIVES

The MUST objectives are specific to Fort James paper converting plant in South Wales, and are mandatory requirements. The MUST criteria were derived from;

a) The current machine control network
b) Current and future application

The three MUST criteria setout below meet the Kepner Tregoe requirements in terms of being mandatory and measurable.

[vi] Characteristics of existing proprietary Network and Plant layout drawings are in Appendix B and C respectively.

1. **Bus Length** – Transmit signals at a distance of up to 300 meters at 115.2 Kbaud rate. The bus length was determined by measuring the distance of the longest cable runs used on the machines within paper converting. The rewinder line was determined to require the longest cable run. Appendix C shows an AutoCAD drawing indicating distances. A further 50% of the length was added for future expansion. The Baud rate of 115.2K is the transmission rate at which the current proprietary RIO network is set and is a minimum requirement.

2. **Node capacity**- Have a minimum capacity of 32 addressable/attachable Nodes. The Node requirement was determined by examining the largest existing proprietary network used within paper converting, counting the Nodes and then adding 25% for future expansion.

3. **Discrete I/O** –Able to connect 1,920 individual discrete I/O to the bus. The I/O requirement was determined by counting the number of I/O racks used on the most populated machine within paper converting then multiplying the total number of racks by the number of I/O slots per rack and the I/O points per slot. (15 racks x 8 I/O modules per rack[vii] x 16 I/O per module = 1,920) this figure would include spare capacity for future expansion as not all slots are used.

4.5 WANT OBJECTIVES

The WANT objectives are generic, not necessarily specific to Fort James paper converting plant – for instance, all factories want low cost easy to use networks.

These are desirable objectives, but not mandatory, some were derived from published works, [Katzel, 1997 pp.92- 96], [Bazany, 1997, pp.88-90], [Peterson, 1998, pp. 61 – 66], [BSI, 2000, pp. 19- 24]; others from examining:

[vii] Using single slot addressing.

- Fundamentals of fieldbus
- Advantages and benefits of fieldbus
- Future strategy of fieldbus

WANT objectives were split into two main categories; Technical characteristics/performance and strategic issues. These categories are further specified below:

4.5.1 Technical Characteristics /Performance has Three Main Sub Sections

1) Physical Characteristics

(a) Capability of configuring various network topologies: Linear trunk, tree, star, ring, mixed.

(b) Choice of physical media. At present the current proprietary network media is dedicated to twin axial. It would be useful to have a variety of choices of physical media. If fiber optic was available it would be possible to run the fiber inside the same trunking as high voltage cables at greater transmission speed and longer distances.

(c) Ability to power devices over a bus cable i.e. over signal wire, and or over separate wires.

(d) Maximum number addressable/attachable nodes.

(e) Minimum transmission rate of 125 Kbaud at 300 meters without repeaters.

2) Transport Mechanism

(a) Configurable operating and signal transmission modes.

(b) Maximum data transfer size.

(c) 100% Determinism.

(d) Detect transmission errors and error correction.

3) Optimal performance

(a) A maximum 12 msec cycle time for 16 Nodes each with 16 digital I/O (256 I/O)

(b) A maximum cycle time 10ms for 16 Nodes each with 8 analogue channels (128 analogue channels)

(c) Block transfers of 128 bytes per Node

4.5.2 Strategic Issues has Three Main Sub Sections

1) Features

(a) Diagnostics/ predictive features.

(b) An open system with multi vendor support.

(c) Maximum number of Vendors offering products for the bus.

(d) Industrial related products compatible with the fieldbus.

(e) Interchangeable/Interoperable products

(f) Ease of use.

1) Costs

(a) low cost per Node

(b) minimal maintenance costs

(c) minimal installation and commissioning costs

(d) minimal overall lifecycle cost

2) Technical/Development support

(a) Efficient and knowledgeable technical/development support

4.5.3 Weighting of WANT Criteria

The weighting index in Table 4.4 is the subjective view of the author based upon his experience and knowledge gained over many years in the paper converting industry. The authors logic is based on the highest weighting being the WANT criteria that would most effect the overall effectiveness of the system and thus the plant. Other weightings are designated relative to this benchmark, for instance the long term economics of a plant (weighted 9.5) is far more important than maintenance costs, which is not the whole picture (weighted 8.5) which in turn is far more important than individually costed items, short term saving (weighted 7.5)

There are 12 criteria in Table 4.4 range from a weighting of 7.5 to 10 and are grouped as follows :-

Group 1 – 1 criteria at weighting of 10

Group 2 – 3 criteria at weighting of 9.5

Group 3 – 2 criteria at weighting of 9.0

Group 4 – 3 criteria at weighting of 8.5

Group 5 - 1 criteria at weighting of 8.0

Group 6 – 2 criteria at weighting of 7.5

a) Group 1 (weighting 10)

The highest weighting was allocated to "industrial products compatible with the fieldbus" because without the necessary range of compatible products the fieldbus would be severely limited in its applications, maybe to the point of being inoperable.

b) Group 2 (weighting 9.5)

The next three objectives have weighting of 9.5 thus reflecting the importance of an overall view based upon long term economics (the long term cost savings as opposed to short-term economic gains); a system that is easy to use (the easier the system is to use the greater the uptime) and use of an open system (The open fieldbus route gives the user a wide selection of equipment at competitive prices, whilst vendor and user groups ensure technology development)

c) Group 3 (weighting 9.0)

Whilst wanting an open system is important another objective is that the devices are interchangeable and interoperable (this reduces downtime and increases the flexibility of the system). What is also of equal importance within this group is the systems ability to detect/predict faults (this reduces the time that would be required to find a system fault). Whist having a system with Diagnostic/Predictive features and an open system is important, it is not so important as, for instance, as having a system with low overall life cycle costs, thus reason for weighting of 9.0.

d) Group 4 (weighting 8.5)

The next consideration is based on economic considerations, but at a lower level.

Technical/Development support, maintenance costs and technical characteristics and performance together play a part in reducing operating expenditure).

e) Group 5 (weighting 8.0)

Having the greatest choice of vendors who offer products for fieldbus will in the long run reduce costs and increase availability and product development, all of which are important considerations in themselves. At the moment the number of vendors offering products is, because of market forces, unpredictable. It was therefore envisaged that the benefits from the objectives in group 4 would outweigh those of this group.

f) Group 6 (weighting 7.5)

This is the lower end of the WANT scale but as indicated by the weighting none the less important.

These are both short term considerations but which would not necessarily effect the long term objectives of the plant. For instance whilst it is desirable that the capital cost expenditure for installation and commissioning is low in the long term this is relative in terms of the life cycle costs.

Table 4-4 *Weighting of WANT Objectives*

WANT OBJECTIVES	WEIGHTING*
Industrial related products compatible with the fieldbus	10
Minimise overall life cycle cost	9.5
Ease of use	9.5
Open system	9.5
Diagnostic/Predictive features	9.0
Interchangeable/Interoperable products	9.0
Technical/Development support	8.5
Minimal maintenance costs	8.5
Optimum Technical characteristic and performance	8.5
Maximum number of vendor offering products for fieldbus	8.0
A low cost per Node	7.5
Minimal installation and commissioning costs	7.5

*Weighting is on a scale of 1 to 10, with 10 reflecting the most important

4.6 EVALUATING CHOSEN ALTERNATIVES AGAINST CRITERIA

Kepner Tregoe states that in order to carry out a valid evaluation then one <u>must</u> be in possession of <u>all</u> the relevant information. Based upon the author's research of device level fieldbuses the following six buses were chosen since according to [Katzel, 1997, p96], [Svacina,1998], [Hoske, 98] and [Pinto, 2000] these are the most frequently quoted between them covering the device level spectrum and all the necessary information was readily available. The Six fieldbuses will be evaluated against the criteria laid out in 4.4. and 4.5.

The six fieldbuses are: -

1. DeviceNet
2. Smart Distributed System (SDS)
3. Interbus-S
4. LonWorks
5. Profibus DP
6. Seriplex

The technical characteristics/performance criteria of each fieldbus will be scored according to the Kepner Tregoe system. The one exception being - the overall ratings are adjusted so that the alternative with the highest weighted score will be adjusted to a score of ten with each of the nominated alternatives proportionally less [see Table 4-19].

4.6.1 Evaluation of Alternatives against Must Criteria

Evaluating alternatives against MUST criteria involves comparing the alternatives against the minimum requirements set out in 4.5.

4.6.1.1 Bus Length[viii]

"Must be capable of transmitting signals up to 300 metres @ 115.2 Kbaud".

Several factors can limit the allowable length of a device bus, for example the attenuation of the data signal flowing through the media, or the ability of the bus power cable to maintain a sufficiently uniform ground potential throughout the length of the bus. In such cases where losses due to attenuation, or insufficient uniformity ground potential are experienced, additional power supplies and or repeaters are used to extend the allowable bus length.

Allowable length for all buses depends on the speed, or baud rate, at which the bus operates. Operations at higher baud rates are generally associated with a decrease in allowable bus length. Table 4-5 lists the maximum allowable distances over which the selected alternatives can operate together with the baud rates associated with these distances.

[viii]The maximum length is defined as the longest allowable signal transmission between the two most separated Nodes.

Table 4-5 *Maximum Allowable Bus Lengths*

Fieldbus	Maximum Bus Length, Meters*	Maximum Data Rate At Maximum Length, Kbaud	Go/No Go
DeviceNet	500	125	GO
SDS	500	125	GO
Interbus-S	400	500	GO
LonWorks	500	1250	GO
Profibus DP	1000	187.5	GO
	400	500	GO
Seriplex	76-1800	10-192	GO

* Using conventional wire media and no repeaters utilized

DeviceNet allowable bus length is operable up to 500 meters at a speed of 125 Kbaud, [ODVA, 1999]. At higher speeds the allowable length drops significantly. The SDS bus is limited to an allowable length of less than 24 meters when operated at its maximum speed of 1000 Kbaud [Hoske, 1998, p10] DeviceNet allows slightly longer bus lengths at intermediate data rates.

Without repeaters Interbus-S has an allowable length of 400 meters at a high data rate of 500 Kbaud. With repeaters it can accommodate Nodes in a ring structure with a total length of up to 8 miles at the same 500 Kbaud rate, due to its rigid message control protocol [Interbus, 2001, p7].

LonWorks has a capability of operating over a distance of up to 2200 meters over conventional wiring media at a speed of 78 Kbaud. At the maximum 1250 Kbaud the bus length is limited to 500 meters. These distances can be increased by adding segments connected through repeaters or by using a fiber optic transceiver [Lonmark, 1999, ch3 p4].

Seriplex has a capability of operating over between 76 and 1800 metres at baud rates respectively between 10 and 192 Kbaud. An interview with a technical member of Seriplex in Raliegh, USA, confirmed that Seriplex will actually run at 115.2Kbaud at 300 metres.

4.6.1.2 Node Capacity

The chosen alternative fieldbuses are required to have a minimum of 31 addressable and physical attachable Nodes. Table 4-6 lists the maximum addressable and attachable Nodes [BSI, 2000, p31], [Moyne,1994]

Table 4-6 *Maximum Addressable and Attachable Nodes*

Fieldbus	Maximum Addressable Nodes	Maximum Attachable Nodes	Go/No Go
DeviceNet	64	64	GO
SDS	126	126	GO
Interbus-S	256	512	GO
LonWorks	32385 per Domain	64 –500	GO
Profibus DP	126 per Link	126	GO
Seriplex	7696	510	GO

4.6.1.3 Discrete I/O Capacity

The chosen alternative device fieldbuses are required to be able to accommodate 1,920 discrete I/O. Table 4-7 lists the maximum theoretical I/O points of each of the chosen fieldbuses.

Table 4-7 *Maximum Theoretical Number of Discrete I/O Points*

Fieldbus	Maximum Number of Discrete I/O points	Go/No Go
DeviceNet	2,048	GO
SDS	1,290,240	GO
Interbus-S	4096	GO
LonWorks	352,000	GO
Profibus DP	124,928	GO
Seriplex	7680	GO

At the high end of the scale SDS has a Node capacity of 64 Nodes per network, the protocol defining multiple embedded objects of up to 32 for each Node. Within each embedded object it is possible to define up to 320 I/O points, thus putting the theoretical number of I/O up to 1,290,240. LonWorks network can handle up to 32,385 Nodes per domain. The LonWorks neuron chip provides the bus with 11 I/O pins for discrete and analog I/O, equating to a possible 352,000 I/O points per domain. This is not the full extent, certain addressing schemes allow up to 32,385 x 32,385 Nodes. Profibus DP has a theoretical maximum of 124,928 I/O points [Regberg, 1998, p37]. Seriplex has a maximum I/O count of 510, 255 Inputs and 255 outputs[ix] non multiplexed or 7680 I/O points fully multiplexed (16 words x 16 channels x 2 input/output) [Seriplex, 1997, p21]. Interbus-S has a maximum of 4096 I/O points [Interbus, 2001, p7]. The lowest theoretical I/O count is that of DeviceNet at 2048 I/O points [Seriplex, 1997, p21].

[ix] Using complementary addressing

4.6.2 Evaluation of Alternatives against the Technical/Performance Criteria

The WANT criteria are evaluated in their respective order as laid out in 4.5

4.6.2.1 Topologies

Six topologies are taken into account when evaluating the alternatives. These are Linear Trunk, Tree, Star, Ring, Closed loop and mixed topologies.

Table 4-8 summarizes the topologies allowed in the alternative fieldbuses [Synergetic, 1999]

Table 4-8 *Topology Capabilities of Fieldbuses Under Evaluation*

Fieldbus	**Allowed Topologies**	Score
DeviceNet	Trunk, Limited Tree	4
SDS	Trunk, Limited Tree	4
Interbus-S	Ring (Physically straight)	4
LonWorks	Trunk, Tree, Star, Loop, Mixed	10
Profibus DP	Trunk, Tree, Star, Mixed without closed Loop	7
Seriplex	Trunk, Tree, Star, Loop, Mixed	10

The CAN buses of DeviceNet and SDS require a linear trunk topology. Off a drop line these buses can perform tree branching, providing that the farthest device is within the allowable branch length. The allowable length of any branch from the main trunk is related to the operating baud rate, stemming from the need for signal reflection suppression. At the lowest speed of 125 Kbaud, SDS branch length is limited to 3 meters per branch, and shorter lengths at higher rates. Whilst with DeviceNet, any individual drop line can be up to 6 meters and at any baud rate. There is a cumulative drop line "budget" for the entire bus, which decreases with higher baud rates i.e. 156 meters accumulative distance of the branches @ 125 KBps down to 39 meters accumulative distance of the branches @ 500 KBps.

Interbus- S has a unique topology and operates on a ring structure, although physically straight. The controller sends data packets in one direction around the ring. Each Node has a silicon chip containing data registers that are indexed one bit place per clock cycle. These data registers receive the packet data, the Node takes action on it where appropriate and then passes the packet data to the next Node and so on until it arrives at the last Node, at which time the return Nodes become simple repeaters. The cable from remote Node to remote Node has a complete set of inbound and outbound wires. Due to its unique mode of operation, Interbus-S cannot accommodate any branching or other topology. The limited topology, imposed by the rigorous data control system, allows for the bus to operate at relatively high speeds over a geographical distance of up to 8 miles [Svancia, 1998, pp 35-41].

LonWorks has very flexible topological requirements. It can accommodate trunks, stars, trees, and loops as well as a combination of these.

Profibus DP can be either configured in trunk, tree and star or a combination of these topologies.

Seriplex can be configured in trunk, star, tree, loop or a combination of these topologies are allowable.

4.6.2.2 Physical Bus Media

In Chapter 3, the specification of the fieldbuses, physical layer sets out the types of cables that can be attached to the bus. These vary from simple unshielded cable to a variety of combinations of twisted pair, either shielded or unshielded and include custom designed cables that fit special cable connections. Some fieldbuses have physical media specifications that cover fiber optic cables and other media-including radio link, powerline, intrinsically safe and IR systems. Table 4-9 summarizes the primary types of cabling recommended for each of the fieldbuses being evaluated.

Table 4-9 *Evaluation of Physical Media*

Fieldbus	Physical Media Used	Score
DeviceNet	Shielded twisted pair for data and unshielded twisted pair for power.	6
SDS	Shielded twisted pair for data and unshielded twisted pair for power.	6
Interbus-S	Shielded twisted pair or fiber optic cable. Cable does not carry power.*	5
LonWorks	Unshielded 2 wire, shielded and unshielded –twisted pair, fiber optic, RF, Powerline, intrinsically safe, and IR.	10
Profibus DP	2 wire unshielded, 2 wire twisted (shielded and unshielded), with separate wires for power and an option of fiber optics, IR for signals.	8
Seriplex	4-wire cable with two conductors for data and two conductors for power enveloped in a single shield.	6

*An optional cable will provide power for devices over separate wires from that of the signal wires.

All CAN buses, DeviceNet and SDS have similar wiring requirements with a twisted pair to carry the data signal and a separate twisted pair for electrical power. Shielded twisted pairs are specified for data lines on DeviceNet and SDS.

Specific terminations are used at the end of the main trunk line to prevent reflections ("ringing") of the data lines. DeviceNet and SDS specify optional standard mini and micro connectors on the ends of drop lines that plug in to standard tee taps. These connectors are typically rated to withstand the ingress of water and harsh environments. The pre-terminated drop lines allow for speedier wiring and a mistake free hook- up [Rockwell, 1997, pp. 7-20], [Honeywell, 1999, pp. 25-35].

The Interbus-S network is divided into two types of buses: the remote bus and the local bus. Each of these carry the same data signal, but at different voltage levels. The remote bus uses RS-485 with a three pair twisted wire with shield and drain. Alternatively, fiber optic media can be used in conjunction with special terminal equipment. The local bus requires five twisted pair wires with shield and drain. I/O modules can be connected directly to the remote bus cable where no power passes through the remote bus cable. Alternatively the local bus can be used to connect directly into the I/O modules. A specific "Bus terminal" module is used to translate the remote bus signals to local bus signals of TTL (CMOS). The advantage of the local bus is that in the case of malfunction it can be by-passed, allowing the remainder of the bus to operate normally [Interbus, 1997, ch3.03].

LonWorks is flexible with regards to the type of physical media that can be included in the network. Multiple twisted pair cables of various types can be used with LonWorks. Media can be mixed with intrinsically safe cabling and transceivers used in parts of the bus, with conventional cabling in the rest. Fiber optic is also an option in areas where EMI/RFI require it. LonWorks also support a "link powered" medium in which communication signals and power to operate the bus devices can be passed over a common pair of wires, although at a relatively low baud rate [LonMark, 1999, ch4, p4].

For signals Profibus DP utilizes two wire unshielded, twisted pairs (shielded and unshielded), with separate wires for power. Fiber optic cabling is available for data transmission [Breeze, 1998, p25].

Seriplex has a custom designed four wire cable that incorporates a pair of wires for data, and a pair for power, all surrounded by a single shield. As Seriplex ignores reflections it does not require resistive terminations at cable ends [Seriplex, 1997, pp. 6-7].

The scoring recorded in Table 4-9 is based on high marks for simplicity and flexibility and lower marks for rigidity in cable requirements that do not further improve bus reliability or operation.

4.6.2.3 Capabilities to Supply Power [BSI, 2000, p31], [Seriplex, 1997, pp. 6-7]

The scoring given in Table 4-10, is relative to the power carrying capacity of the bus and relates to the needs of the Nodes that would likely populate the bus. Simplicity of cabling and connecting devices to a bus is achieved only if the power lines are contained in the same cable as that of the signal wires. If power is not available over the bus cabling, or there is not sufficient power, then separate power lines will be required and thus wiring becomes more involved, requiring larger volumes of connectors and connections.

Table 4-10 *Ability of Fieldbus to Supply Power*

Fieldbus	Over Signal Wires	Over Separate Wires	Score
DeviceNet	No	Yes	5
SDS	No	Yes	5
Interbus-S	No	Yes	3
LonWorks	Yes*	Yes	10
Profibus DP	No	Yes	5
Seriplex	No	Yes	5

* Optional Cables

The simplest form of cabling is when power is provided over the signal conductors. LonWorks, where power can be supplied either over the signal conductors (PLT-22 only) or separate conductors in the bus cable, received the highest score [LonMark 1999,ch3, p4]. The remaining buses, with exception of Interbus-S, are only able to support power over separate conductors in the bus cabling, thus only receive half the rating of LonWorks. Interbus-S does not fall into the standard capability outlined above. Optional cable can be used to enable it to carry power on the bus, although it is expensive and used mainly for waterproof terminated I/O modules.

4.6.2.4 Maximum Number of Addressable/Attachable Nodes

The maximum number of attachable and addressable Nodes allowed were discussed in depth earlier in this section. The scoring in Table 4-11 is based on the maximum number of attachable and addressable Nodes in relation to fieldbus type.

Table 4-11 *Maximum Attachable/Addressable Nodes*

Fieldbus	Maximum Addressable Nodes	Maximum Attachable Nodes	Score
DeviceNet	64	64	6
SDS	126	126	8
Interbus-S	256	512	9
LonWorks	32385 per Domain	64 –500	10
Profibus DP	126 per Link	126	8
Seriplex	7696	510	9

4.6.2.5 Bus Length

The maximum bus length for a given baud rate was discussed previously in this section. Table 4-12 lists the scores ascribed to the fieldbuses chosen for evaluation with respect to each other and against the WANT criteria being a minimum of 300 meters @ 115.2Kbaud.

Table 4-12 *Maximum Allowable Bus Lengths*

Fieldbus	Maximum Bus Length, Meters*	Maximum Data Rate At Maximum Length, Kbaud	Score
DeviceNet	500	125	4
	250	250	
	100	500	
SDS	500	125	4
	180	250	
	90	500	
	23	1000	
Interbus-S	400	500	3
LonWorks	2000	78	
	500	1250	10
Profibus DP	1200	93.75	7
	1000	187.5	
	400	500	
	200	1500	
	100	12000	
Seriplex	1800	10	9
	240	64	
	120	100	
	76	192	

* Using conventional wire media and no repeaters utilized.

4.6.2.6 Modes of Operation

The modes of operation are discussed in depth when evaluating determinism further on in this section. Summarized in Table 4-13 are the capabilities of the device fieldbuses under evaluation with regard to their configurability in each of these modes.

Table 4-13 *Configurable Operating Modes*

Fieldbus	Master/Slave	Peer to Peer	Master/Slave and Peer to peer	Score
DeviceNet	Yes	Yes	Yes	10
SDS	Yes	Yes*	Yes	7
Interbus-S	Yes	No	No	3
LonWorks	Yes	Yes	Yes	10
Profibus DP	Yes	No	No	3
Seriplex	Yes	Yes	Yes	10

*In specifications, has not been implemented as yet.

All devices under study are capable of transmitting one or more of the following types of signals:

- **Change of state-** A signal is transmitted only when data changes.
- **Cyclic-**Data is transmitted at a fixed rate.
- **Time Synchronized-**Signal transmission only in assigned time slots.
- **Polled-**Upon request, data is transmitted to requester.
- **Multicast-** One data transmission is usable by multiple devices.
- **Broadcast-**One data transmission usable by any device on the bus.

Maximum marks were scored by DeviceNet, SDS, Interbus-S, LonWorks and Profibus DP because they are capable of carrying all of the signal types investigated for this study. Seriplex, on the other hand is only able to transmit certain of these types of signals, [Regberg, 1998, pp. 70-71].

Table 4-14 summarizes the findings on the various capabilities of the buses to carry any or all of these types of signal transmissions.

Table 4-14 *Configurable Transmission Mode*

Fieldbus	Change of state	Cyclic	Time Sync	Polled	Multicast	Broadcast	Score
DeviceNet	Yes	Yes	Yes	Yes	Yes	Yes	10
SDS	Yes	Yes	Yes	Yes	Yes	Yes	10
Interbus-S	Yes	Yes	Yes	Yes	Yes	Yes	10
LonWorks	Yes	Yes	Yes	Yes	Yes	Yes	10
Profibus DP	Yes	Yes	Yes	Yes	Yes	Yes	10
Seriplex	No	Yes	Yes	No	No	Yes	5

4.6.2.7 Data Transfer Size per Message Segment

Table 4-15 lists the maximum data size of the fieldbuses under evaluation.

As it can handle a data packet length of up to 244 bytes Profibus DP scored the highest mark, whilst LonWorks scored marginally less at 228 bytes. The CAN Buses of DeviceNet and SDS can handle 8–byte variable message with fragmentation for larger packets. The data capacity of Seriplex for a single frame is 255 input bits and 255 output bits. Whilst this is a considerable capacity for discrete I/O devices, the number of analogue signals within a single frame is limited to 15 (16-bit) inputs and 15 outputs, [Synergetic, 1999]. Seriplex is capable of employing address multiplexing as a means of expanding the data capacity. In address multiplexing, multiple devices share the same signal addresses. Individual signals at the shared addresses are distinguished by assigning each one of 16 unique multiplexed channels. Each data frame transmits data for a single multiplex channel. Using the multiplex channel extends the addressing range from 8 bits to 12 and results in an increase in a single buses data capacity from 510 signal bits to 7,680 signal bits, a factor of fifteen approximately, [Seriplex, 1997, pp. 15-18]. Interbus-S transfer data is divided into two basic types: first, the I/O or Process data second the messages and parameters. The process data being able to transfer up to 64 bytes and the parameter or message data 246 bytes, [Interbus, 2001, pp. 9-10].

Table 4-15 *Maximum Data Transfer Size*

Fieldbus	Maximum Data Transfer per Message Segment	Score
DeviceNet	8 Bytes variable message	8
SDS	8 Bytes variable message	8
Interbus-S	1-64 Bytes real time data/device, Parameter data channel 246 Bytes, 512 In & 512 Out per system	7
LonWorks	228 Bytes	9
Profibus DP	244 bytes	10
Seriplex	255 bits, 7680 bits/transfer fully multiplexed	7

4.6.2.8 Determinism

The "determinism" of a bus relates to the degree of assurance that a packet of data which is sent over the bus arrives at its inherent target in a specified and repeatable amount of time. Principles in bus access methods are discussed in detail in Chapter 3 section 3.6.1.

Some buses operate exclusively in Master/Slave mode. This means that the controller initiates all conversations whilst other devices on the network speak only when spoken to. Essentially this eliminates messages being delayed, or lost messages being sent. Such an operation is highly deterministic and the degree of determinism might be rated at 100% deterministic for that reason, but response time suffers.

Another way of being deterministic is by synchronizing operations, having each device deliver its report in a specified time slot. This allows peer to peer as well as Master/Slave conversations, while at the same time maintaining a deterministic system. Interbus-S and Seriplex operate in the synchronous mode and are therefore considered to be fully 100% deterministic, [Svacina, 1998, pp 40-43].

With DeviceNet and SDS it is possible to operate on a form of contention based principle known as "carrier sense multiple access with bit arbitration" (CSMA/BA). Any device can transmit when a bus is clear. Some collisions will occur, but CAN messages include a 19-bit header with several bits reserved to prioritise the message.

The priority resolution is performed within 23 clock cycles, which equates to 46 microseconds for a bus running at 500 Kbits/sec. The actual degree of determinism is difficult to calculate since it depends on the degree of traffic on the bus, which in turn relates to the number and types of sensors and other devices on the bus, the baud rate at which the bus is operating, and what is happening within the process being monitored by these devices. In the event driven non scheduled mode the CAN buses of SDS and DeviceNet are said to be less than 100% deterministic, [Regberg, 1998, pp. 50-52].

Even though DeviceNet and SDS can operate in the CSMA mode, there is a distinction between each of the buses that effect determinism. DeviceNet has peer to peer capabilities in which a peer can send a message directly to another peer. As explained earlier, such messages may collide and thus the bus becomes less than 100% deterministic. DeviceNet can also operate in a Master/Slave mode, in which a

Slave will transmit only when requested by the Master. In this mode DeviceNet is 100% deterministic. SDS operates in a Master/Slave mode, which can also be described as a "peer-Master" mode. Field devices can initiate communications, but only with the Master controller. It is still possible, therefore, that two devices can start to send messages at the same time, resulting in these messages colliding. Therefore in this type of Master/Slave (peer to peer) mode 100% determinism cannot be attained.

LonWorks is a network that can operate either in Master/Slave operation, which is 100% deterministic, or in peer to peer operation, which due to inevitable data collisions, is less deterministic. See Table 4-16

Table 4-16 *Degree of Determinism*

Fieldbus	Degree of Determinism	Score
DeviceNet	100% Master/Slave mode, Under 100% for Peer to Peer	8
SDS	Under 100%	7
Interbus-S	100%	10
LonWorks	100% Master/Slave	8
Profibus DP	100%	10
Seriplex	100%	10

4.6.2.9 Detecting Transmission Errors and Error Correction

The CAN buses of DeviceNet and SDS make use of a built in error-checking device inherent within the CAN protocol. This includes CRC checking and also allows each transmitting device to monitor the actual transmission on the bus to catch errors between what was actually transmitted and what is received. In addition, the CAN buses incorporate several error prevention protocols, including bit wise arbitration, acknowledgement messages and bit stuffing. Bit stuffing is used in the case where a long series of 0's or 1's are part of a message. In such cases a bit of opposite value is inserted into the message to help keep the various devices on the bus synchronized.

Profibus DP utilizes CRC checking with a Hamming distance of four for its error Checking method, [Breeze, 1998, p26].

Interbus-S also uses a CRC check for error detection. Interbus-S operates on a ring basis where each device on the ring receives a message and transmits it in one complete scan of the ring. The CRC is performed just once per complete ring cycle. When an error is detected, Nodes do not use the data, all wait for another complete cycle, [Interbus, 2001, ch3.0.5].

LonWorks also uses a CRC error detection system in the bus data link layer. As in the CAN buses, the CRC check is applied to each message packet as it is transmitted. In addition, LonWorks incorporates error correction coding (ECC) at the application level, [LonMark, 1999, ch3, pp. 2-3].

Seriplex incorporates CDR. There are other checks and logic functions to prevent and detect errors. These include:

- Bus Integrity check by the host interface at the end of every scan period
- Bus integrity check by every device on the bus at the end of every scan
- Optional data echo feature allows host to verify that the receiving device correctly received data, [Seriplex, 1997, pp. 11-12].

Table 4-17 lists the error checking and correcting methods of the fieldbuses under evaluation. In general, all these buses rate fairly high in being able to prevent and detect transmission errors at the data link level. At the data link layer the CAN protocol seems particularly robust. The additional error detection and correction incorporated into the application layer of these buses should permit use even in the most critical applications.

Table 4-17 *Error Checking and Correcting Methods*

Fieldbus	Error Checking Systems	Score
DeviceNet and SDS	Uses CAN capabilities for bit wise arbitration, acknowledge, bit stuffing and frame checking. Error detection by CRC check and monitoring of bus by transmitting device.	10
Interbus-S	CRC on each bus scan.	9
LonWorks	CRC checking of data packet and ECC at application level.	10
Profibus DP	CRC checking with a Hamming distance = 4.	8
Seriplex	CDR data link layer error detection. Bus integrity checks over scan period. Optional data echo feature.	6

4.6.2.10 Performance

Cycle times of the fieldbuses under evaluation were tested under three conditions

1. 256 Discrete (16 Nodes with 16 I/O)
2. 128 Analogue (16 Nodes with 8 I/O)
3. Block transfer of 128 bytes 1 Node

The overall performance ratings are shown in Table 4-18, [Synergetic,1999]

Table 4-18 *Performance of Fieldbuses*

Fieldbus	Cycle time: 256 discrete 16 Nodes with 16 I/O's	Cycle time:128 analogue 16 Nodes with 8 I/O's	Block transfer of 128 bytes 1 Node	Score
DeviceNet	2.0 ms Master-Slave polling	10 ms Master – Slave polling	4.2 ms	8
SDS	<1 ms, event driven	5 ms polling @ 1 Mbps	2 ms 1 Mbps	9
Interbus-S	1.8 ms	7.4 ms	140 ms	7
LonWorks	20 ms	5 ms @ 1 Mbps	5 ms @ 1 Mbps	8
Profibus DP	Configuration Dependant Typ < 2 ms	Configuration Dependant Typ < 2 ms	TBA	10
Seriplex	1.32 ms @ 200 Kbps, Master – Slave	10.4 ms	10.4 ms	9

4.6.2.11 Composite Scoring

Overall technical performance of the buses is listed in Table 4-19. The adjusted score will be used as part of the overall rating of the fieldbuses see Table 4-30 (Technical Characteristics/Performance).

Table 4-19 *Overall Score for Technical/Performances of Chosen Fieldbuses*

Criteria	DeviceNet	Interbus-S	LonWorks	Profibus DP	SDS	Seriplex
Topologies	4	4	10	7	4	10
Physical Media	6	5	10	8	6	6
Power Capabilities	5	3	10	5	5	5
Node capacity	6	9	10	8	8	9
Bus Length	4	3	10	7	4	9
Operation Modes	10	3	10	3	7	10
Signal Transmission Modes	10	10	10	10	10	5
Data Transfer Size	8	7	9	10	8	7
Degree of Determinism	8	10	8	10	7	10
Error Checking	10	9	10	8	10	6
Performance	8	7	8	10	9	9
TOTAL SCORE	**79**	**70**	**105**	**86**	**78**	**86**
Total Adjusted to 10 Maximum scale	**7.5**	**6.6**	**10**	**8.2**	**7.4**	**8.0**

4.6.3 Evaluating Alternatives against the Strategic Criteria

All the information found in 4.6.3 to 4.6.3.11 and the scores contained in Tables 4.20-4.29 were taken from a survey provided by Venture Development Corporation (VDC) of Devices/Sensor fieldbuses [Regberg, 1998] Whilst the scores are comprehensive there was no data to substantiate them. Because no other unbiased research was available at the time the author was forced to take the data on face value. VDC were contacted with regards to more information but were not willing to release further details as they were commercially sensitive.

The survey carried out by VDC were compiled using the following primary research methods

- Mail survey sent to 9,000 end users
- 66 machinery OEM interviews
- 35 instrumentation and control OEM (device manufacturers) interviews; and
- 22 interviews with protocol developers, interface chip suppliers, and representatives on device/sensor bus organisations, and standard groups.

End users and machinery OEM covered a broad range of discrete manufacturing and process industry applications, as well as those combining both (figures 4.2 and 4.3).

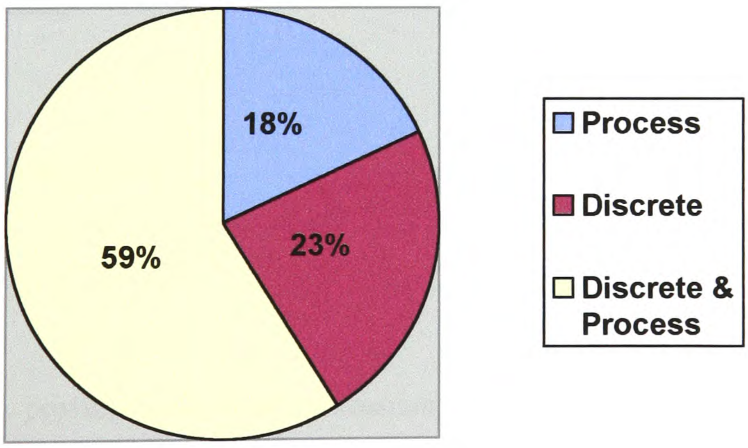


Figure 4-2 *End users applications*

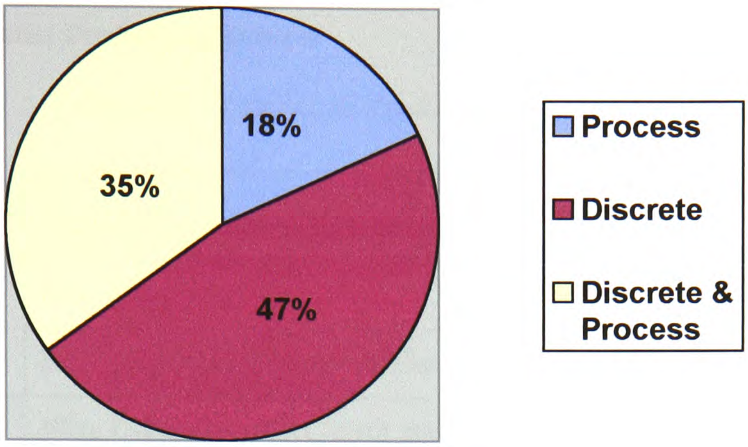


Figure 4-3 *Machine OEMs applications*

The instrumenetation/Control OEM interviews covered a broad range of products used in industrial controls including manufactures of:

- Actuators:
- Bar code scanners;
- Operator interfaces;
- PLCs;
- PCs;
- Motor controls and drives
- Sensors and
- Switches

Whilst this survey provides a wealth of information it would be unsound to use it as a sole means of selection. It was for this reason a fieldbus trial was carried out and the results compared to those found in the VDC survey (see Chapter 5 section 5.3.4).

4.6.3.1 Diagnostic/ Predictive Features

Table 4-20 *Diagnostic/Predictive Features*

Fieldbus	Diagnostic/Predictive features	Score
DeviceNet	Bus Monitoring	10
SDS	Bus monitoring, Diagnostic Slave	6
Interbus-S	Wire Location of CRC error and cable break Module and I/O channel diagnostics	5
LonWorks	Database of CRC errors and device errors	3
Profibus DP	Station module and channel diagnostics	7
Seriplex	Cabling problems	1

4.6.3.2 Open System

DeviceNet has an open specification, Governing Standard ISO 11898 and 11519. All 300 ODVA members are within the industrial sector; ODVAs membership criteria accept manufacturers only. With 1,498 registered specification holders in the industrial sector, there are several levels of membership: Limited Associate, Full membership and Founding membership all of which require annual subscriptions. It is not essential for a company to join ODVA. CAN chips are available from 17 suppliers. In order to certify a DeviceNet product as interoperable a 'terms of use agreement" form must be signed with the ODVA in order to get a Vendor ID number. Under this agreement a vendor must agree immediately to cease shipping products if a problem is detected.

SDS is an open specification with no fees, or royalties. Governing Standard BS EN 50325-3 (In process of publication). SDS has a partner program for vendors and has recently inaugurated the Smart Society, the SDS user organization. SDS has distributed over 450 sets of specifications with more than 100 companies developing compatible products.

Interbus-S Governing Standards DIN 19258 type 8, EN 50.254 volume 2, IEC 61158 Type 4[x]. The Interbus Club has more than 700 manufacturers and more than 400 members worldwide. Among its members, approximately 15% are end-users, 80% manufacturers and 5% integrators. Again there are no licensing or royalty fees. The interface chip is licensed by Phoenix Contact. Interbus-S has compliance testing facilities within Europe for the interface chip.

LonWorks, the manufacturers of the Neuron chip, are licensed by Echelon, who receives royalties from the sales. LonWorks Governing standards ANSI/EIA-709.1 (ASHRAE of BACnet). Founded in 1994, the LonMark Interoperability Association is an independent group of more than 200 manufacturers, system integrators and end-users.

Profibus DP Governing Standards EN 50170, DIN 9245 part 3 and IEC 61158 Type 3. 17 Profibus User Organizations support Profibus technology on seven continents worldwide. To date the PTO has 620 members, including 130 from the United States; of those 620 members, 75 are end-users, 275 are manufacturers, 125 are academics and 145 are integrators. At present there are in excess of 1,130 Profibus products from more than 270 manufacturers. Membership is scaleable, based on the size of a

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[x]Information contained within the BSI guide to evaluation of fieldbus protocols-Selecting the best fieldbus for your application, 9.2 The relationship between EN 50170, EN 50524 and IEC 61158, Page 25 is incorrect in relation to the additional number and type reference now incorporated within IEC 61158.

company. Passive (non voting members) pay a nominal fee, while companies with over 100 employees pay a fairly large annual fee.

Seriplex Square D owns the patents to the technology and licenses the ASIC chip to manufacturers. Seriplex has no Governing Standard. There are no restrictions on manufacturers who incorporate the chips into their products. The specifications are published free of charge[xi]. To date approximately 60 manufacturers provide Seriplex compliant products. The STO (Seriplex Technology Organization) has over 50 members. For annual subscriptions of $500, STO members receive technology marketing, promotional and development tools, support and training.

The policies of the respective buses when evaluated were found to be quite similar. As such, a score of 10 is awarded across the board.

4.6.3.3 Number of Vendors Offering Products for Fieldbuses

Figure 4–4 shows the percentage of vendors interviewed by VDC, who currently supply, develop, or are considering developing products which will interface with device buses by type. The highest percentage of vendors are for DeviceNet, followed by Profibus DP, Interbus-S and SDS. Table 4-21 lists respective scores.

[xi] Can be downloaded from the Internet at http/WWW.seriplex.org/

Table 4-21 *Number of Vendors offering Products*

Fieldbus	Score
DeviceNet	10
SDS	9
Interbus-S	8
LonWorks	7
Profibus DP	8
Seriplex	5

4.6.3.4 Industrial Related Products Compatible with Fieldbus

VDC analysis of products available, under development or being considered for development by instrumentation/control OEM's, the following scores relative to each fieldbus were assigned for product availability in terms of satisfying the broadest range of the needs in industrial control applications. Table 4-22 shows the relative scoring for each bus.

Table 4-22 *Relative Scoring of Availability of Compatible Products for Fieldbuses*

Fieldbus	Score
DeviceNet	10
SDS	6
Interbus-S	5
LonWorks	3
Profibus DP	7
Seriplex	1

4.6.3.5 Interchangeable/Interoperable Products

Table 4-23 shows the relative scores for interchangeability of products per fieldbus type [Regberg, 1998].

Table 4-23 *Relative Scores for Interchangeability of Products per Fieldbus Type*

Fieldbus	Score
DeviceNet	10
SDS	7
Interbus-S	7
LonWorks	10
Profibus DP	8
Seriplex	8

4.6.3.6 Ease of Use

The scoring contained in Table 4-24 is based upon comments of end-users, machinery OEM's, instrumentation/control OEMs and integrated circuit manufacturers.

Table 4-24 *Ease of Use*

Fieldbus	Score
DeviceNet	7
SDS	7
Interbus-S	5
LonWorks	5
Profibus DP	6
Seriplex	10

4.6.3.7 Costs Per Node

Table 4-25 contains scoring relating to the added costs associated with hardware required to interface devices to the device/sensor buses. The respective scoring is based upon information obtained by VDC from end-users, machinery OEMs, instrumentation/control OEMs, protocol developers, bus associations and the interface chip manufacturers.

Table 4-25 *Low Cost Per Node*

Fieldbus	Score
DeviceNet	7
SDS	7
Interbus-S	6
LonWorks	5
Profibus DP	5
Seriplex	10

4.6.3.8 Installation and Commissioning Costs

Table 4-26 shows the relatives scores for installation and commissioning costs [Regberg, 1998].

Table 4-26 *Installation and Commissioning Costs*

Fieldbus	Score
DeviceNet	7
SDS	8
Interbus-S	5
LonWorks	5
Profibus DP	6
Seriplex	10

4.6.3.9 Maintenance Costs

The scoring in Table 4-27 is based upon the experiences and perception of interviewees carried out by VDC relative to reliability, extent of maintenance required and diagnostics available to assist in maintenance.

Table 4-27 *Maintenance Costs*

Fieldbus	Score
DeviceNet	10
SDS	9
Interbus-S	6
LonWorks	6
Profibus DP	6
Seriplex	7

4.6.3.10 Overall Cost

Overall cost takes into account the total perceived cost of purchase, training, installation, maintenance and operation. The scoring is based upon the overall comments of end-users, machinery OEMs, instrumentation/control OEMs and integrated circuit manufacturers. (Table 4-28)

Table 4-28 *Low Overall Costs*

Fieldbus	Score
DeviceNet	8
SDS	8
Interbus-S	7
LonWorks	7
Profibus DP	7
Seriplex	10

4.6.3.11 Technical/Development Support

The scores contained in Table 4-29 is based upon the extent to which interviewees indicate the degree and acceptability of the technical support offered by fieldbus organizations or protocol developers.

Table 4-29 *Technical/Development Support*

Fieldbus	Score
DeviceNet	10
SDS	7
Interbus-S	8
LonWorks	7
Profibus DP	8
Seriplex	6

4.6.4 Overall Ratings of the Alternatives

Table 4-30 gives the overall ratings of the alternative fieldbuses. DeviceNet with the highest score is selected as the tentative choice. SDS with the next highest score ranked second, indicating that CAN based fieldbuses have an overall superior balance i.e. performance and strategic issues than that of the other alternatives. Profibus DP, Seriplex, Interbus-S and LonWorks ranked 3rd to 6th respectively.

TABLE 4-30 *OVERALL RATINGS OF SELECTED FIELDBUSES*

	Weighting	DeviceNet	SDS	Interbus-S	LonWorks	Profibus DP	Seriplex
Industrial related products compatible with filedbus	10						
Score		10	6	5	3	7	1
Weighted Score		100	60	55	30	70	10
Overall cost	9.5						
Score		8	8	7	7	7	10
Weighted Score		76	76	66.5	66.5	66.5	95
Ease of Use	9.5						
Score		7	7	5	5	6	10
Weighted Score		66.5	66.5	47.5	47.5	57	95
Open system with Multi Vendor Support	9.5						
Score		10	10	10	10	10	10
Weighted Score		95	95	95	95	95	95
Diagnostic/Predictive Features	9.0						
Score		10	6	5	3	7	1
Weighted Score		90	54	45	27	63	9.0
Interchangeable/interoperable Products	9.0						
Score		10	7	7	10	8	8
Weighted Score		90	63	63	90	72	72
Technical/Development Support	8.5						
Score		10	7	8	7	8	6
Weighted Score		85	59.5	68	59.5	68	51
Minimal Maintenance Costs	8.5						
Score		10	9	6	6	6	7
Weighted Score		85	76.5	51	51	51	59.5

TABLE 4-30 (CONTINUED) *OVERALL RATINGS OF SELECTED FIELDBUSES*

	Weighting	DeviceNet	SDS	Interbus-S	LonWorks	Profibus DP	Seriplex
Technical Characteristics/Performances	8.5						
Score		7.5	7.4	6.6	10	8.2	8.0
Weighted Score		63.75	62.9	56.1	85	69.7	68
Number of Vendors offering products for the bus	8.0						
Score		10	9	8	7	8	5
Weighted Score		80	72	64	56	64	40
Cost per Node	7.5						
Score		7	7	6	5	5	10
Weighting		52.5	52.5	45	37.5	37.5	75
Installation and Commisioning costs	7.5						
Score		7	8	5	5	6	10
Weighted Score		52.5	60	37.5	37.5	40	75
TOTAL WEIGHTED SCORE		**936.25**	**797.9**	**693.6**	**682.5**	**753.7**	**744.5**
OVERALL RANKINGS		**1**	**2**	**5**	**6**	**3**	**4**

4.7 POTENTIAL RISKS

The potential risks listed below were generated using guidelines setout in section 4.2 of this Chapter.

1. Rockwell being merged or taken over
2. Incorrect selection due to lack of or missing information
3. Reliability and accuracy of data used to select a tentative alternative
4. Reliability of the Fieldbus
5. Future direction of fieldbuses

Having established the potential risks, each risk is evaluated against the likelihood of it occurring and the adverse consequences should it occur.

With the purchase of Allen-Bradley, Rockwell moved out of aerospace, fax and modem-chips and into industrial automation. Allen-Bradley had been a privately owned company prior to being acquired by Rockwell. It was a valuable asset that Siemens, Emerson as well as other players had tried, but failed to add to their portfolio.

Rockwell's annual sales have declined from approximately $13 billion (1995) to $10.3 billion (1996), $7.8 billion (1997), $6.7 billion (1998), $7 billion (1999) and leveled out in 2000. This decline was thought to be attributed to diversifying into unrelated businesses and corporate strategy.

With the news that it could not meet its forecasts in September 2000[Industrial computing, 2001], Rockwell stocks fell by approximately 30%. The market is now capped at around $5 billion, leading analysts to believe that Rockwell is a prime target for a takeover bid by one of the major institutions.

Whilst there is a potential risk of a takeover, there are only a limited number of companies that are large enough or healthy enough to afford it. Allen-Bradley still remains a prize asset [Pinto, 2000]. If a take over was ever to take place it is the opinion of the author that the new company would continue to play a major role in supporting the ODVA as DeviceNet has experienced an exponential growth since its conception in 1984, with little sign of the adoption rate slowing down [ODVA press release, March 2000].

A potential risk to the tentative choice failing to meet the criteria of low overall cost is the lack of comparative costing against current networks used within the paper converting process. For this reason an independent study was carried out on the comparative costing of installing a system using Direct (Centralized) I/O, Flex I/O networked to Allen-Bradley's Proprietary Remote I/O and the tentative choice DeviceNet. The methodology and findings from this independent costing study are set out in section 4.8.

The missing information relates to one criterion- backward compatibility. As this is seen as a low Want criteria it was decided it would not effect the outcome by its omission in the Kepner Tregoe evaluation process.

Another potential risk surrounds the possibility of erroneous data having being used to evaluate the strategic criteria i.e. data gathered from case studies, interviews, independent network organizations etc. It is for this reason, as well as to establish the reliability of the fieldbus itself in terms of uptime of the network, data flow, diagnostics etc, that a fieldbus trial was carried out on the tentative choice. The conclusions from the field trial will either endorse or not the findings of the selection. The number of alternatives used in the selection process made it impractical, both logistically and economically to carry out a field trial on all of them. The methodology and findings from the study are detailed in Chapter 6.

The introduction of EtherNet/IP which is supported by the ODVA, the independent organization for DeviceNet, ControlNet International (CI) and Industrial Ethernet Association, has raised many concerns for the future of DeviceNet. In order to allay the concerns of both existing and potential customers and Vendors a press release was issued by the ODVA on March 17, 2000. The press release stated that in light of the imminent introduction of Ethernet/IP the question was asked would DeviceNet become obsolete the answer was a definite "No". The reasons given were that there is no existing network, which is comparable in terms of robustness or efficient data handling to DeviceNet. Unlike Ethernet, DeviceNet can supply power and communications through the same cable, other factors such as security and network performances are also concerns. The ODVA stated that since its inception, DeviceNet has experienced exponential growth – an adoption rate that shows little sign of slowing. The reasons given are that DeviceNet and EtherNet/IP are complimentary, not competitive, technologies. (Figure 4-4) was produced by the ODVA detailing each network and showing how they coexist to deliver shop floor to office communications [ODVA ,March 2000].

	DeviceNet	**EtherNet/IP**
Target Applications	Puts simple devices on a network that replaces hardwiring	Ties to plant management systems (e.g. materials and planning)
	Provides device diagnostics	Controls, configures and collects data on a single high speed network
	Controls, configures and collects data	Networks time-critical applications that don't require a user established schedule
Typical Devices	Processor/adapters	Computers
On the Network	Valves, pushbuttons, sensors, motor starters	Processors and HMIs
	Simple drives	I/O and adapters
Geography covered	Single work area or machine	Entire plant can easily be covered using routers, bridges and switches
	Limited distance due to CAN, speed and power	Connections between plants are possible via high speed data lines and satellites
	Multiple networks may feed into and communicate across a common backbone	Non manufacturing networks need to be separated to eliminate unnecessary traffic
Perceived and	Low perceived cost due to CAN chip cost	Perceived cost is low due to commercial components
Actual Cost	Perceived and actual costs are the same- low	Actual may be high due to point-to-point architecture and switch cost
Parts required to build a Network	Main network cable carries power and signal (4 wire)- available in flat or round media	10 Mbaud Bus configuration includes thick or thin cable in star topology
	Devices can hang directly on the wire or can be attached to a drop cable	Routers, bridges, switches and other elements are commercially available
	Connectors are available in open and sealed designs	100 Mbaud configured in star topology
	Power supplies are distributed on the network based on the number of devices and power requirements.	Switches are required for control applications Routers, bridges, switches and other elements are commercially available

Figure 4-4[xii] *Ethernet/IP and DeviceNet Comparison*

[xii] Source: ODVA web site

It is the opinion of the author, and also that of many commentators, that industrial Ethernet will become the next, de facto standard for industrial communications (as detailed in Chapter 2 section 2.5), thus causing the eventual demise of DeviceNet. This scenario will apply to all six alternatives. As a consequence the introduction of Ethernet has very little bearing on the eventual outcome of the selection. The significant reduction in installation costs detailed in section 4.8 outweighs in the short to medium term the risk imposed by the introduction of Industrial Ethernet.

4.8 COST ANALYSIS

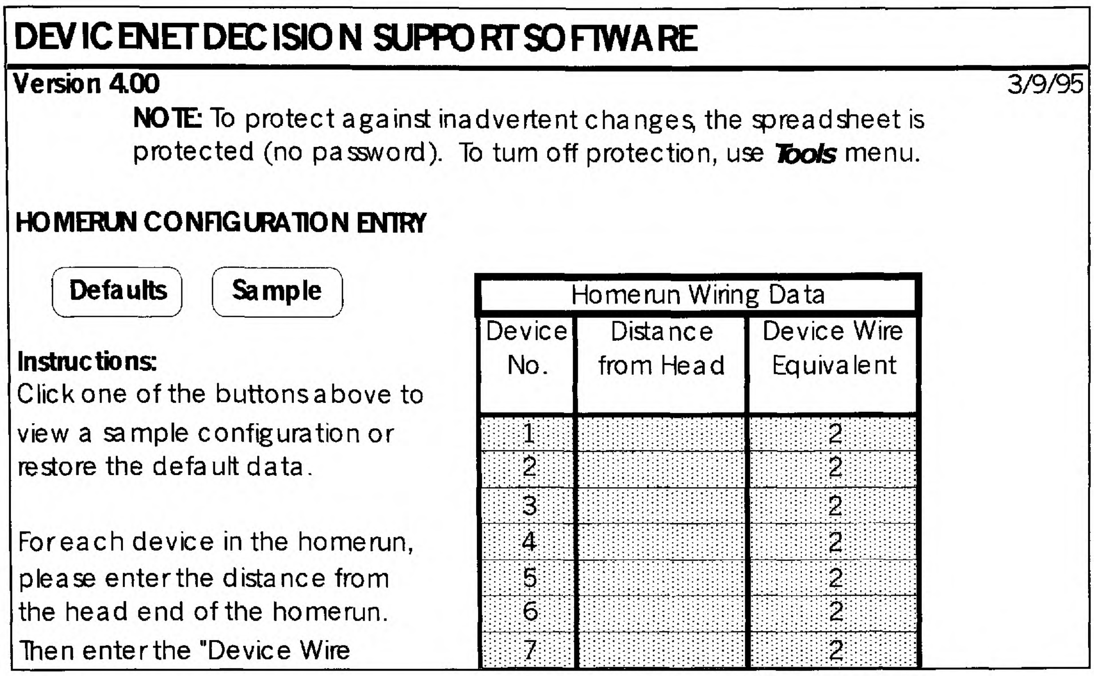
In order to eliminate the potential risk detailed in section 4.7 of this Chapter a cost analysis was carried out to evaluate the cost savings relative to the existing installed networks. The evaluation was carried out using DeviceNet cost comparison software, a copy of the instruction manual is included in Appendix B. Dr R.S.H.Piggin reported an overall accuracy of within 5% when using this software tool to calculate the Warwick University DeviceNet demonstrator [Piggin, 1999].

4.8.1 Cost Comparison Software

Below are some key points with regards to the cost comparison software.

Functionality

By entering device data and distance from control panel (Figure 4-5) the DeviceNet Toolkit spreadsheet calculates three different installed costs: one using traditional hardwire I/O, one using distributed Flex I/O and the third using distributed devices on DeviceNet.



DEVICENET DECISION SUPPORT SOFTWARE

Version 4.00 3/9/95

NOTE: To protect against inadvertent changes, the spreadsheet is protected (no password). To turn off protection, use *Tools* menu.

HOMERUN CONFIGURATION ENTRY

Defaults Sample

Instructions:
Click one of the buttons above to view a sample configuration or restore the default data.

For each device in the homerun, please enter the distance from the head end of the homerun. Then enter the "Device Wire

Homerun Wiring Data		
Device No.	Distance from Head	Device Wire Equivalent
1		2
2		2
3		2
4		2
5		2
6		2
7		2

Figure 4-5 *Initial Screen*

Comparison models

The models used are simplified representations of installations figures 4-6 to 4-8 (one homerun is allowed, multiple runs can be calculated by adding the results of individual runs, remembering to remove the cost of the Scanner for the additional runs);

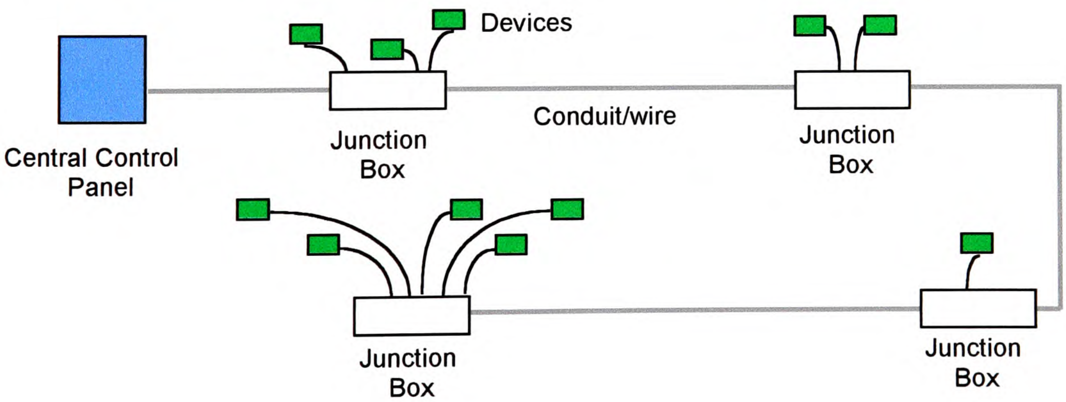


Figure 4-6[xiii] *1771/1746 Direct Model*

[xiii] Figures 4-6 to 4-8 are extracts from the manual in Appendix B

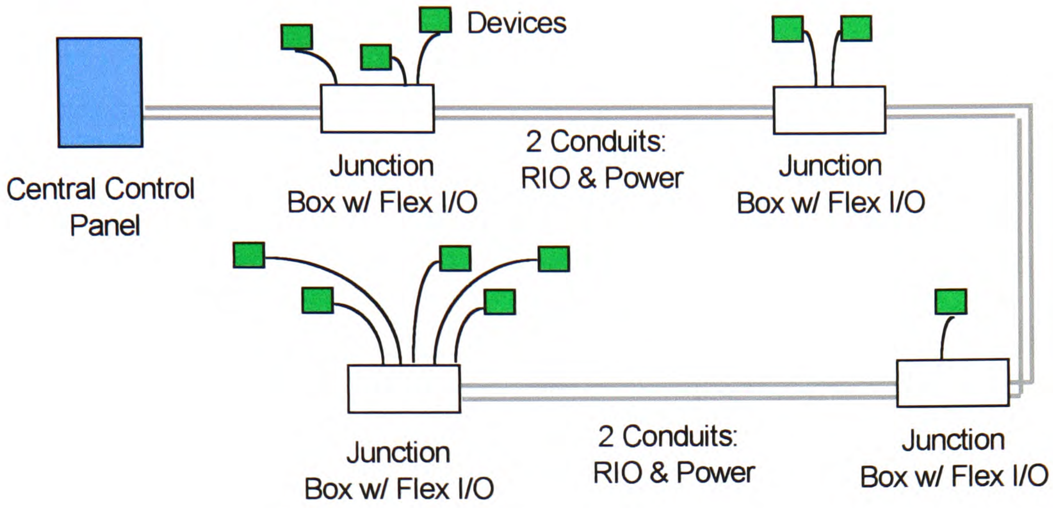


Figure 4-7 *Flex I/O Model*

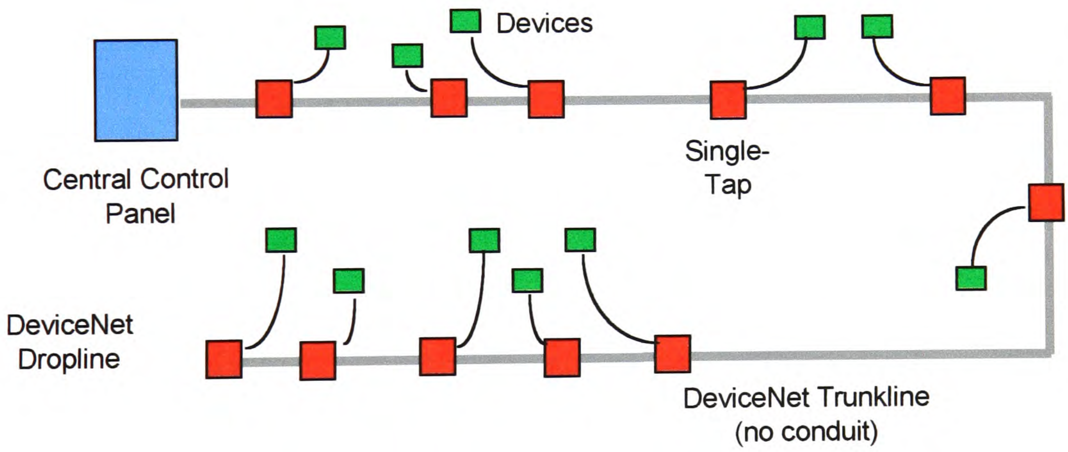


Figure 4-8 *DeviceNet Model*

Model Assumptions

Table 4-31 *Model Assumptions*

Assumptions	1771/1746 Direct	Flex I/O	DeviceNet
Homerun Wiring Method	Wire pulled in conduit	2 conduits, 1 power and 1 blue hose	DeviceNet trunk cable - no conduit
Device Wiring Method	Junction boxes with terminal blocks; flex cable to device	Junction boxes with Flex I/O blocks, flex cable to device	Single or 8-tap DeviceNet taps (as you choose), flex dropline to device
Spacing of junction boxes or taps	Function of device spacing and max. device cable length (default = 15 ft.)	Function of device spacing and max. device cable length (default = 50 ft.)	Same as device spacing
I/O Equipment cost	Based on "device equivalent wires" and "I/O points per module" (default 16)	Based on "device equivalent wires" and "I/O points per module" (default 16)	1 DeviceNet scanner card included

The following items are included in the cost models:

- 1771/1746 and Flex I/O equipment on a "cost per I/O point" basis
- Conduit, wire, junction boxes, terminal blocks
- DeviceNet trunk cable, taps, scanner module
- Labour to install conduit or trunk cable, pull and terminate wiring

The following items are NOT included in the cost models as they are assumed to be roughly equivalent between models:

- PLC processor
- Device drop cables
- Main control panel enclosure and terminal blocks

Spreadsheet Use

Distance from head end (control panel) is entered in feet along with the device wire equivalent. The device wire equivalent is a representation of a device's complexity e.g. a single pole switch is considered a 2 wire device (requiring one input point). Table 4-32 contains a selection of common examples (these assume basic hardwire functionality, whereas DeviceNet often offers more).

Table 4-32 *Device Wire Equivalent and Device Incremental Cost*

Device	Device Wire Equivalent	DeviceNet Incremental Cost
Photocell	3	£17
Proximity Sensor	3	£43.8 (DeviceLink)
Redistation	4 (3 signal and common)	£135
2705-DN42	7	£135
Motor Drive	6 (start, stop, reverse and reference)	GK5 -£200 Bulletin 160 -£250
SMP-3	6	£200
Flex i/o (16 inputs)	18 (plus power and common)	0 (same price as RIO)
Valve Manifolds	Number of signals + 1 (common)	£375 - £500

If the scanner used is a 1746 SLC then the "Approximate I/O Cost (per point)" value must be changed in the "Material Units Costs" (see spreadsheet/Appendix B).

Some of the assumptions used in the spreadsheet may be altered (these are shaded green). It has been necessary to update fields such as labour rates, material costs and spare capacity to tailor further the results to the application and company policies, thus providing more accurate figures.

DeviceNet incremental costs need to be calculated and entered into the material units section of the spreadsheet. This represents the additional cost of the DeviceNet interface for each device. The spreadsheet defaults to £30, the additional cost of a photoelectric sensor. Typical figures for these are shown in Table 4-33 (inclusive of global agreement discounts).

When using a combination of DevicePorts and taps, the number of taps used will be reduced by 8 for each 8 way ports.

Changes to the Software

A number of value changes were incorporated into the software comparison table to reflect the current status, these included:

- Revised material costs
- Revised labour costs
- Revised required spare capacity has been re-aligned to reflect company policy
- Revised Number of I/O points (per I/O card) to reflect single slot addressing when using Direct I/O
- Revised scanner card pricing to include global discount agreement with Rockwell

Using an existing application within the paper converting process two hypothetical scenarios were calculated to evaluate the comparative installed costs of the three systems:

Completed comparison costing spreadsheet calculations, drawings, I/O listings and material costs for each of the scenarios are included in Appendix B

1. The first scenario is the replacing of the saw controls on converting line 10. This being the shortest cable run on a rewinder line. Two calculations were performed.
   - Direct comparison without incremental cost of DeviceNet devices (Premium)
   - Including incremental costs

2. The second scenario is the replacement of the external unwind controls on converting line 10. This being the longest cable run on a rewinder line. Two calculations are performed.
   - Direct comparison excluding any incremental cost per device
   - Including intelligent sensors and I/O Modules

Replacing Line 10 Rewinder Saw Controls:

The first of the two calculations works out an installed cost for a direct replacement of the existing system in terms of discrete I/O being non-intelligent, therefore incurring no premium in terms of incremental cost per device were included in the calculations.

The completed spreadsheet and calculations in Table 4-33 show DeviceNet to be 70% less expensive to install than Direct and 20% less than Flex I/O.

The greatest savings are the hardware costs with a saving of £617 over both Direct and Flex I/O.

This software does not allow for the indirect cost saving in production time of the three systems. Calculations were carried out to discover the comparison in cost savings across all three systems. Overheads were obtained from company's statistics for calendar year 2000. Calculations are as follows:

1. Direct- 255 minutes wiring labour time x £2.78/minute overhead = £709
2. Flex I/O- 192 minutes wiring labour time x £2.78/minute overhead = £534
3. DeviceNet- 60 minutes wiring labour time x £2.78/minute overhead = £167

It can be clearly seen that a further indirect saving of £542 and £367 respectively over Direct and Flex I/O systems can be achieved.

The results shown for both direct and indirect savings indicate clearly that DeviceNet would be the right option to install in this particular situation.

Table 4-33 *Installed Cost Comparison Excluding Premium*

	Direct	**Flex I/O**	**DeviceNet**
Labour Calculations:			
Wiring Labour time (Minutes)	255	192	60
Total Wiring labour cost	£98	£74	£23
Labour cost to install conduit	£80	£0	£0
Labour cost to install DeviceNet trunkline			£60
Labour costs to install junction boxes	£13	£13	£59
Total labour costs before rework	£191	£87	£141
Total cost before rework	£19	£3	£3
Total labour cost	£210	£90	£144
Material Calculations:			
Total incremental device cost	£0	£0	£0
Total cost of junction boxes	£16	£32	
Total DeviceNet connector cost			£517
Total RIO or DeviceNet cable cost		£0	£25
Total Terminal block cost	£68		
Total wire cost	£379	£13	
Estimated I/O hardware cost	£960	£960	£343
Total conduit cost	£66	£133	
Total material cost	£1,490	£1,138	£885
Total Installed Cost	**£1,700**	**£1,200**	**£1,000**

(Figures rounded to the nearest £100)

A second calculation was carried out using intelligent I/O devices. The incremental cost per device was calculated at £25.30 for this particular application (33 discrete I/O x £17 Premium[xiv] + £375 Premium for manifold/37 Number of total I/O). The results in Table 4-34 show DeviceNet is now double the price compared with that shown in

[xiv] Incremental costs taken from Table 4-33

Table 4-33 whilst Direct and Flex I/O remain constant. Taking into account the savings in overheads, as previously calculated, DeviceNet is still found to be 25% more expensive to install.

Table 4-34 *Installed Cost Comparison Inclusive of Premium*

	Direct	Flex I/O	DeviceNet
Labour Calculations:			
Wiring Labour time (Minutes)	255	192	60
Total Wiring labour cost	£98	£74	£23
Labour cost to install conduit	£80	£0	£0
Labour cost to install DeviceNet trunkline			£60
Labour costs to install junction boxes	£13	£13	£59
Total labour costs before rework	£191	£87	£141
Total cost before rework	£19	£3	£3
Total labour cost	£210	£90	£144
Material Calculations:			
Total incremental device cost	£0	£0	£925
Total cost of junction boxes	£16	£32	
Total DeviceNet connector cost			£517
Total RIO or DeviceNet cable cost		£0	25
Total Terminal block cost	£68		
Total wire cost	£379	£13	
Estimated I/O hardware cost	£960	£960	£343
Total conduit cost	£66	£133	
Total material cost	£1,490	£1,138	£1,810
Total Installed Cost	**£1,700**	**£1,200**	**£2,000**

(Figures rounded to the nearest £100)

Replacing Line 10 External Unwind Controls:

The first of the two calculations works out an installed cost for a direct replacement of the existing system in terms of discrete I/O being non-intelligent, therefore carrying no premium in terms of incremental cost per device were included in the calculations.

The results in Table 4-35 show that DeviceNet to be 13% less expensive to install than Flex I/O and 87% less expensive than the Direct method, both figures exclude lost production.

Table 4-35 *Installed Cost Comparison Excluding Premium*

	Direct	**Flex I/O**	**DeviceNet**
Labour Calculations:			
Wiring Labour time (Minutes)	381	282	96
Total Wiring labour cost	£146	£108	£37
Labour cost to install conduit	£133	£0	£0
Labour cost to install DeviceNet trunkline			£100
Labour costs to install junction boxes	£13	£13	£91
Total labour costs before rework	£292	£121	£227
Total cost before rework	£29	£5	£5
Total labour cost	£321	£126	£232
Material Calculations:			
Total incremental device cost	£0	£0	£0
Total cost of junction boxes	£16	£32	
Total DeviceNet connector cost			£854
Total RIO or DeviceNet cable cost		£0	£41
Total Terminal block cost	£102		
Total wire cost	£940	£22	
Estimated I/O hardware cost	£1,344	£1,344	£343
Total conduit cost	£122	£133	
Total material cost	£2,524	£1,619	£1,238
Total Installed Cost	**£2,800**	**£1,700**	**£1,500**

(Figures rounded to the nearest £100)

Comparing these savings with those shown in Table 4-33, Flex I/O has faired better by +7%, which can be attributed to the extra increase in the number of taps required by the DeviceNet network. Conversely, the Direct method has seen an increase of 17% which is attributed to the extra wiring costs.

Taking into account the accumulative overhead costs, due to downtime for installation DeviceNet is now only 40% less expensive to install than flex I/O and over twice as cheap to install than the Direct method. From these figures it can be seen the reduction in wiring labour time accounts for around a 27% saving in cost when employing DeviceNet as compared with Direct and Flex I/O.

The second calculation was carried out using Intelligent I/O, the incremental cost was calculated at £21.00. The resultant costs as seen in Table 4-36 show the cost to install DeviceNet and Direct method to be the same, but 64% more expensive than Flex I/O.

Table 4-36 *Installed Cost Comparison Inclusive of Premium*

	Direct	**Flex I/O**	**DeviceNet**
Labour Calculations:			
Wiring Labour time (Minutes)	381	282	96
Total Wiring labour cost	£146	£108	£37
Labour cost to install conduit	£133	£0	£0
Labour cost to install DeviceNet trunkline			£100
Labour costs to install junction boxes	£13	£13	£91
Total labour costs before rework	£292	£121	£227
Total cost before rework	£29	£5	£5
Total labour cost	£321	£126	£232
Material Calculations:			
Total incremental device cost	£0	£0	£1,323
Total cost of junction boxes	£16	£32	
Total DeviceNet connector cost			£854
Total RIO or DeviceNet cable cost		£0	£41
Total Terminal block cost	£102		
Total wire cost	£940	£22	
Estimated I/O hardware cost	£1,344	£1,344	£343
Total conduit cost	£122	£221	
Total material cost	£2,524	£1,619	£2,561
Total Installed Cost	**£2,800**	**£1,700**	**£2,800**

(Figures rounded to the nearest £100)

DeviceNet was 3% cheaper when compared with the figures shown in Table 4-34; these figures exclude overheads through lost production. When taking overheads into account, DeviceNet was found to be only 23% more expensive to install than Flex I/O. After evaluating the costs extracted from the two scenarios, three major factors stand out as contributing to the cost effectiveness of a network: distance, incremental cost per device and labour time. Further calculations were carried out to evaluate the effects of two of these factors.

Figures 4-9 shows a graph depicting the effect distance has upon costs. Calculations were made on the basis of a fixed number of I/O arbitrarily set at sixty three, the maximum number of devices that DeviceNet is allowed and no incremental costs, thus simulating an installation using conventional non intelligent discrete I/O.

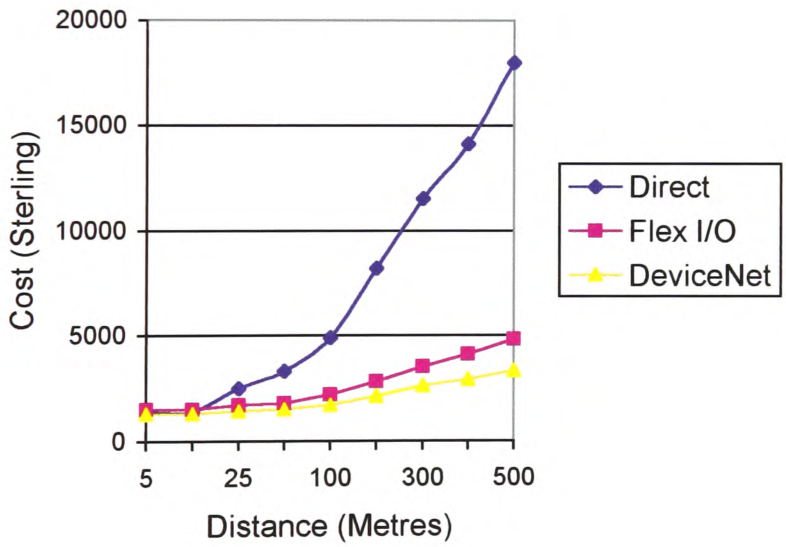


Figure 4-9 *Ratio of Distance to Cost*

Costs were calculated at intervals of between 5 and 500 meters.

Figure 4-9 shows that Direct I/O is the most effected by distance. This was also the case when comparing the two previous scenarios. Flex I/O and DeviceNet on the other hand remain proportionately constant, due mainly to their similarity in cable costs.

Next, Figure 4-10 shows the relationship between the premium per device and cost. The calculations were based on a fixed distance of 250mtrs and 63 devices. As DeviceNet is the only network subjected to an incremental cost both Direct and Flex I/O stay constant. In this particular scenario it is clear that DeviceNet is cost effective up to £15.00 incremental cost/device compared to Flex I/O. The figure of £15.00 is just short of the incremental cost of £17.00 for a sensor. If the overheads are taken into account this figure would rise proportionately with the size of the network.

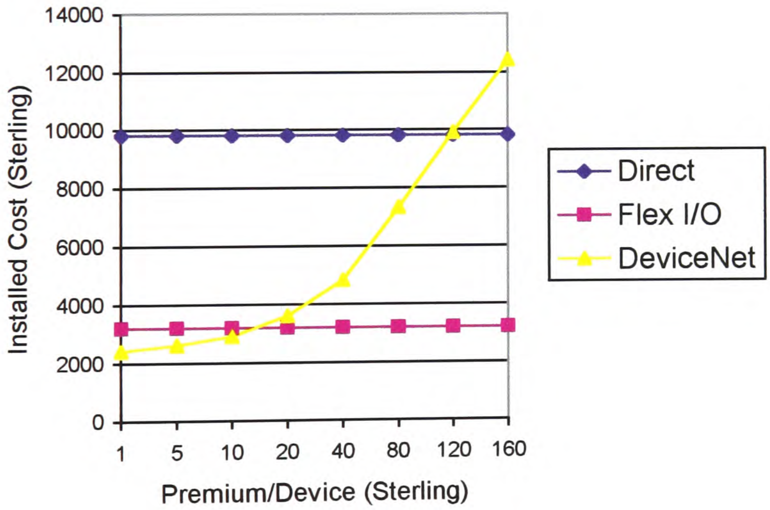


Figure 4-10 *Ratio of Premium per Device to Cost*

The labour time to cost ratio was not calculated as it can vary substantially with each application i.e. new installation may not require an overhead calculation, or retrofit work maybe carried out during factory shutdown periods. This factor is still worth bearing in mind when costing a network.

4.9 SUMMARY

The use of Kepner Tregoe in the selection process on one hand proved to be invaluable, with the results correlating closely to those found by VDC[xv]. On the other it could be argued that its methodology is too open to missuse. Whilst every effort was made to be completely unbiased, the process itself is so subjective in setting the importance of criteria and the evaluation process that it leaves itself open for individuals with particular preferences to manipulate the outcome.

The potential risk analysis generated five factors, which may influence the final decision. The risk of bankruptcy was disregarded as being highly unlikely, although there is a slight possibility of a takeover of Rockwell due to under performance and ever decreasing profits. The consequence of a takeover was judged as having very little impact on the final decision as it is believed that due to the exponential growth of DeviceNet the new owner of Rockwell would still fully support the ODVA.

The future of DeviceNet, like all the six alternatives, will be influenced by the introduction of Industrial Ethernet. Whilst the introduction of Ethernet may cause the demise of many of the alternatives, including DeviceNet, it was felt that the installed cost reductions (detailed in section 4.8 of this Chapter) outweigh in the short to medium term the risk imposed by the introduction of Industrial Ethernet.

[xv] Many commentators may argue the results of the study by VDC were influenced by the majority of end–users in America already standardizing on Rockwell products. The same picture was mirrored by a study by Arc where Profibus was found to be the most popular fieldbus in Europe. (Europe being dominated by Siemens)

The cost analysis software tool highlighted the benefits of DeviceNet in terms of installed cost saving, over Flex I/O and Direct, DeviceNet proving to be on average over the two alternatives (excluding overheads) 78.5% less expensive to install when using conventional non intelligent discrete I/O. It was also found to be cheaper to install than either Flex I/O or Direct up to an incremental cost per device of £15 and £120 respectively. Whilst these two sets of figures show a decrease in the cost of installing DeviceNet it is difficult to draw a parallel with figures published by the institutions and organizations as parameters surrounding these calculations were not provided. The cost comparison software tool is in some ways too simplistic and thus neglects to take into account several factors that could influence the final decision for instance:

- Overheads
- Savings on drawing and design time
- Savings over life cycle due to greater uptime
- Savings due to greater diagnostic features of DeviceNet
- Cost of training
- Cost of software and diagnostic tools

In order to assess the reliability of the fieldbus itself, and the accuracy of the data used in selecting the tentative choice, a fieldbus trial was carried out. The next chapter sets out in detail the fieldbus evaluation trial, method, results and conclusions.

CHAPTER 5

FIELDBUS EVALUATION TRIAL

In order to corroborate the findings of Chapter 5 a small scale fieldbus evaluation trial was carried out on the selected fieldbus, thus limiting further the potential risk of adverse consequences when installing/selecting the fieldbus. Sets out in this chapter are the method, results and conclusions of the fieldbus evaluation trial.

5.1 METHOD

The trial was carried out in two parts. First the starter kit was constructed and tested prior to installation. The second part was a field trial using the starter kit on Number 10 Rewinder Line which is located in the converting department of the South Wales plant (Figure 5-1). As a result of the recent upgrade of line 10 and the fact it was retrofitted with Rockwell's proprietary remote I/O network and series 5 PLC (details of the control layout can be found in appendix C) it was the opinion of the author that this line would give a good comparison between a proprietary network and a device level fieldbus.

The rewinder line produces toilet rolls for the consumer market. The process commences with the unwinding of single ply toilet tissue from two parent reels placed on two unwind stands (known as external and internal unwinder's), thereby producing a two ply product. As the two tissue plys are brought together they are rewound to the correct diameter and perforation length using the rewinder section (Figure 5-2). The log, as it is known, is then passed to the tailsealer where the tail is glued. From here it is transferred to an accumulator. The final stage, prior to it being conveyed to the packaging machines is its passage through the log saw (Figure 5-3). The log saw cuts the log into the finished length using a spinning blade and rotating head. The average output for this line is 32 tonnes a day.

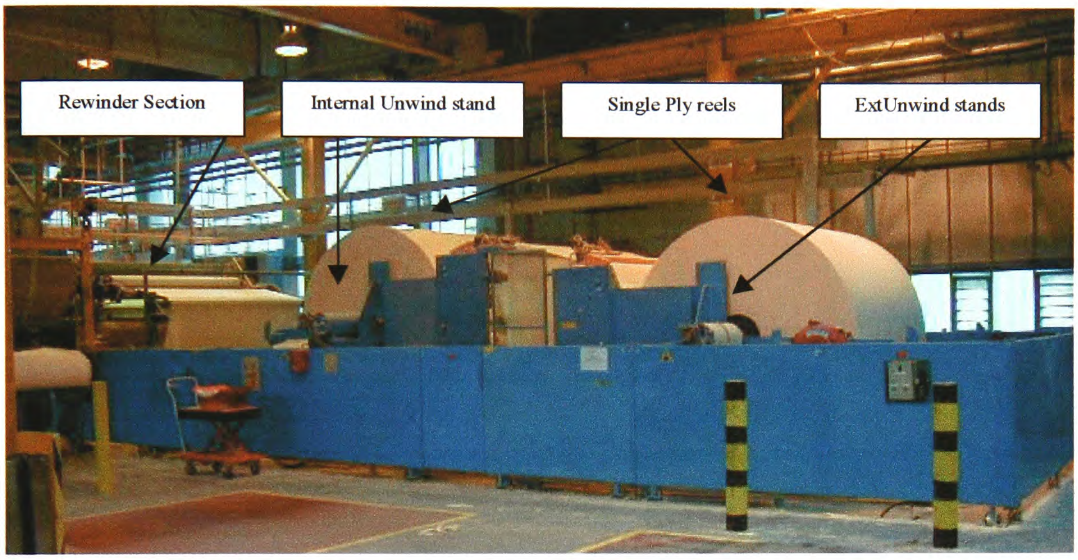


Figure 5-1 *Line 10 Unwind Stands and Rewinder Section*

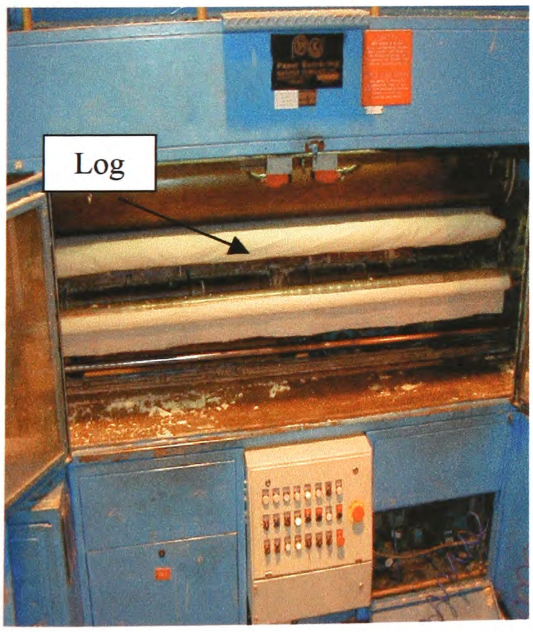


Figure 5-2 *Line 10 Rewinder*

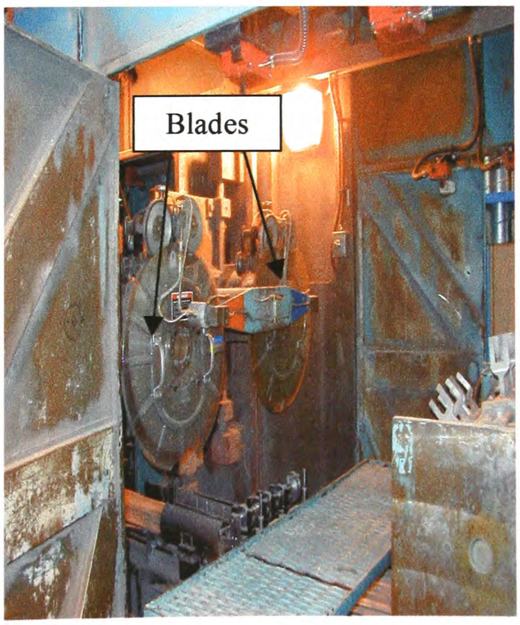


Figure 5-3 *Line 10 Saw*

The `controls and ancillary equipment are housed in an MCC (Main Control Cabinet) Figure 5-4. The line is controlled by a Rockwell PLC-5 (Figure 5-5) processor with point to point wiring connecting all devices with exception of the drives within the main control cabinet. The drives and field I/O are connected via the central processor to Rockwell's proprietary network- Remote I/O.

Figure 5-4 *Line 10 MCC*

Figure 5-5 *Line 10 Control Cabinet*

Set out below is the sequence in which the trial was conducted.

- Construction of starter kit
- Field trial
    - Planning
    - Constructing a PLC Program
    - Installation and commissioning
- Monitoring/Results

5.1.1 Constructing the Starter Kit

As previously mentioned, the initial stage of the trial was to construct offline the DeviceNet starter kit. This was achieved by following the step by step instruction contained within the Rockwell "Getting Started Manual".

The manual provides 19 predetermined steps for constructing and testing the starter kit. The 19 steps are as follows:

1) Organize and identify contents of starter kit
2) Assemble the KwikLink media System
3) Attach the flat media cable to the Armor MaXum base and attach the seal
4) Connect 24V DC power supply and ground network
5) Connect the PC to the controller interface (1770 KFD)
6) Connect controller interface to scanner
7) Install the demo version of RSNetWorx for DeviceNet
8) Start RSLinx
9) Select the DeviceNet Driver appropriate for the controller interface
10) Go online and browse the network
11) Minimize RSLinx
12) Start RSNetworx and browse the DeviceNet network
13) Commission ArmorBlock MaXum
14) Connect and node commission one device at a time
15) Automap a scanlist, modify and download the configuration to the scanner.
16) Edit I/O parameters for the Inductive Proximity
17) Start RSLogix 5
18) Download demonstration ladder logic
19) Experimenting

1. Organize Contents- The contents were identified and organized as per instructions, Figure 5-6 shows the contents of the starter kit.

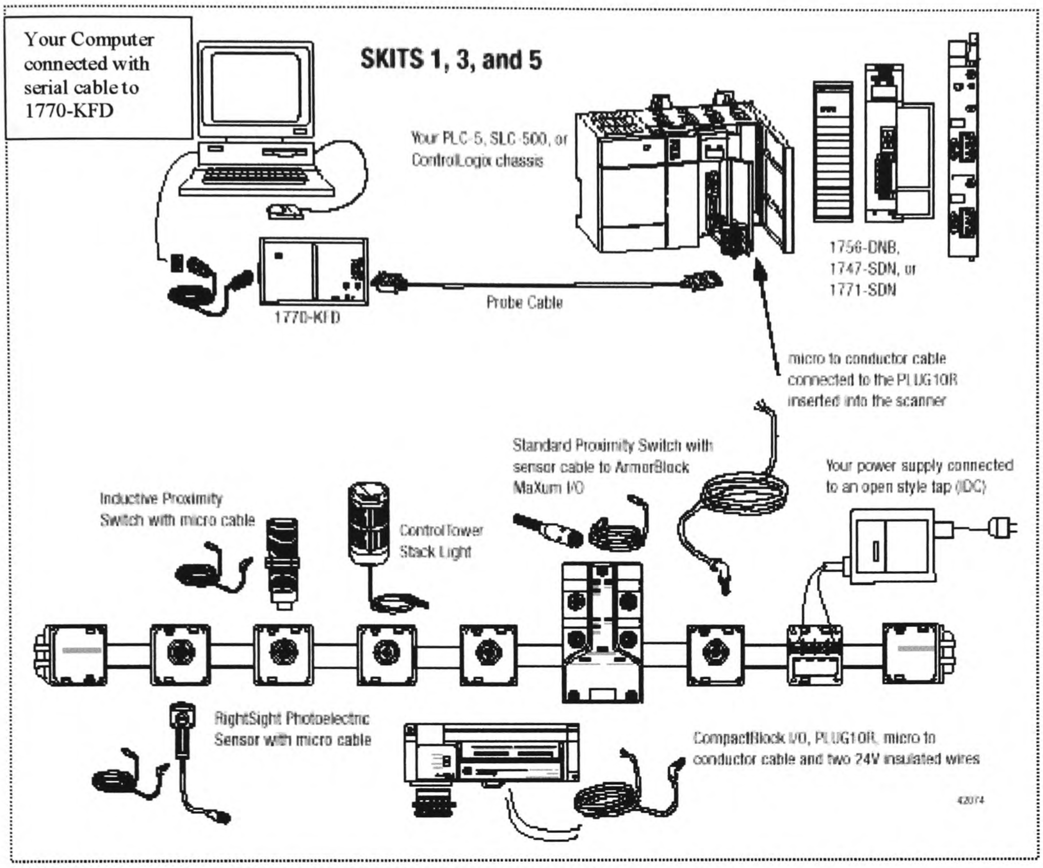


Figure 5-6 *Contents of DeviceNet Starter Kit*

2. Assemble KwikLink Media- The assembly of the KwikLink Media system (Figure 5-6) using the KwikLink trunk cable and KwikLink taps, referred to as Insulation displacement connectors (IDC).

Attaching the taps to the media involved:

- Laying the cable in the hinged base thus ensures the correct orientation of the keyed cable.
- Closing the hinged assembly to the first latched position, this loosely holds the connector in position. The second position closes the connector tightly[i]. Tighten

---

i Note: this requires greater pressure

the two screws at the center points of the hinge and latch sides of the base. (Tighten down latch side first).

- Drive down the IDC contacts by tightening two screws
- Attach the top of the micro/open/terminator to the base by lining up the keyed rectangular holes on the base and snapping into position.

Figure 5-7 shows a KwikLink tap IDC Node connector prior to it being sealed over the KwikLink flat cable media. Figure 5-8 shows three different IDC connectors attached to the media.

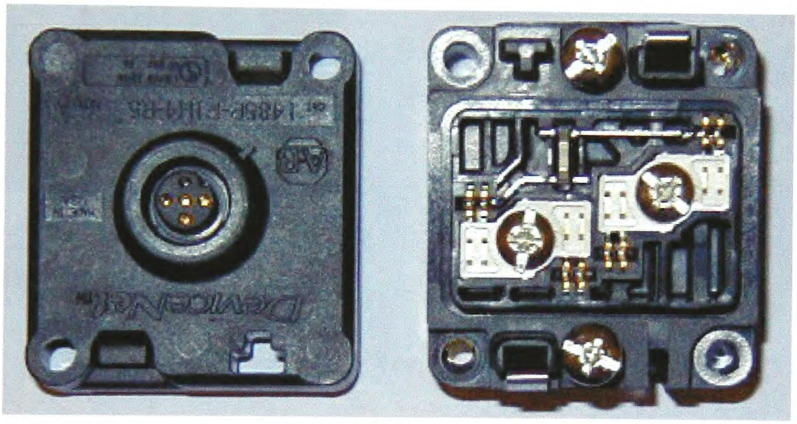


Figure 5-7 *KwikLink Tap (IDC) Micro Quick Disconnect*

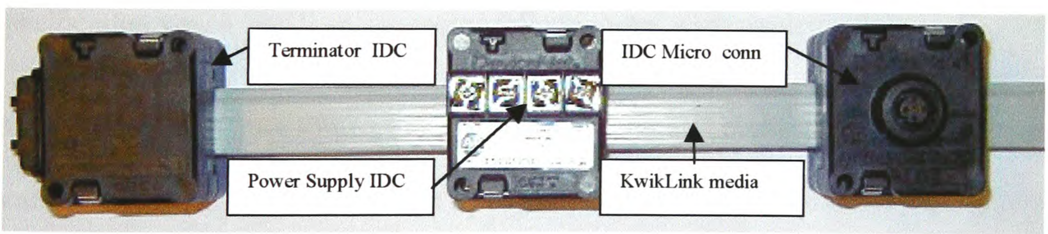


Figure 5-8 *Assembled KwikLink Media System*

3. Connect ArmorBlock to Media- Because the starter kit is intended for use in a simple application the outputs were not powered from the ArmorBlock MaXum. In real applications it is the power cable from the ArmorBlock MaXum that would actually power the outputs. The steps for connecting the node are the same as those discussed above. The one important point to note is that it is imperative that the network cable is placed in the correct slot (Figure 5-9).

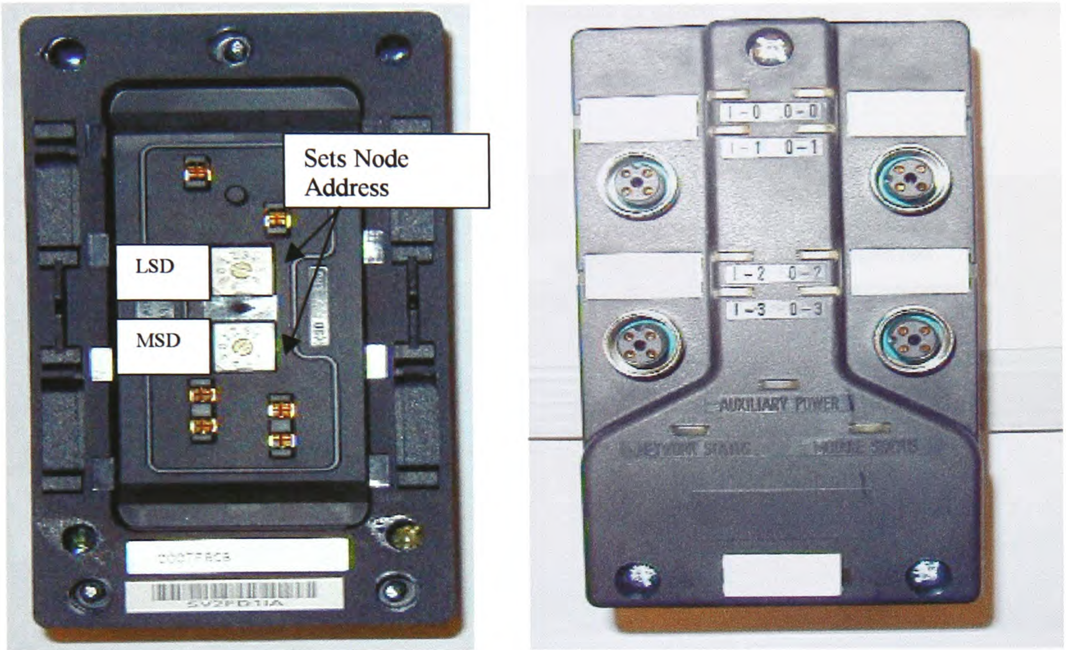


Figure 5-9 *ArmorBlock MaXum*

4. Connect Power Supply- A power supply was selected that met the DeviceNet specification which was then connected following the step instruction[ii].

5-6. Connect PC to controller interface/ Connect controller interface with scanner –The initial step was to set the address of the scanner using the dip switches located on the side of the scanner, and then insert into the PLC-5 processor chassis [Rockwell, 1997]. The scanner is the DeviceNet master (controller interface) coordinating all data to and from all devices on the DeviceNet network. In this trial the DeviceNet data is transferred from a PLC-5 and 1771-SDN via block transfers and

[ii] See Figure 6-9 for a picture of the IDC power supply Node

discrete I/O Transfers. These data were then used in the ladder logic program to carry out the actual functional control. For the purpose of this trial the address was set to 0[iii].

The 1770-KFD interface module was connected (Figure 5-10) using the steps set out below.

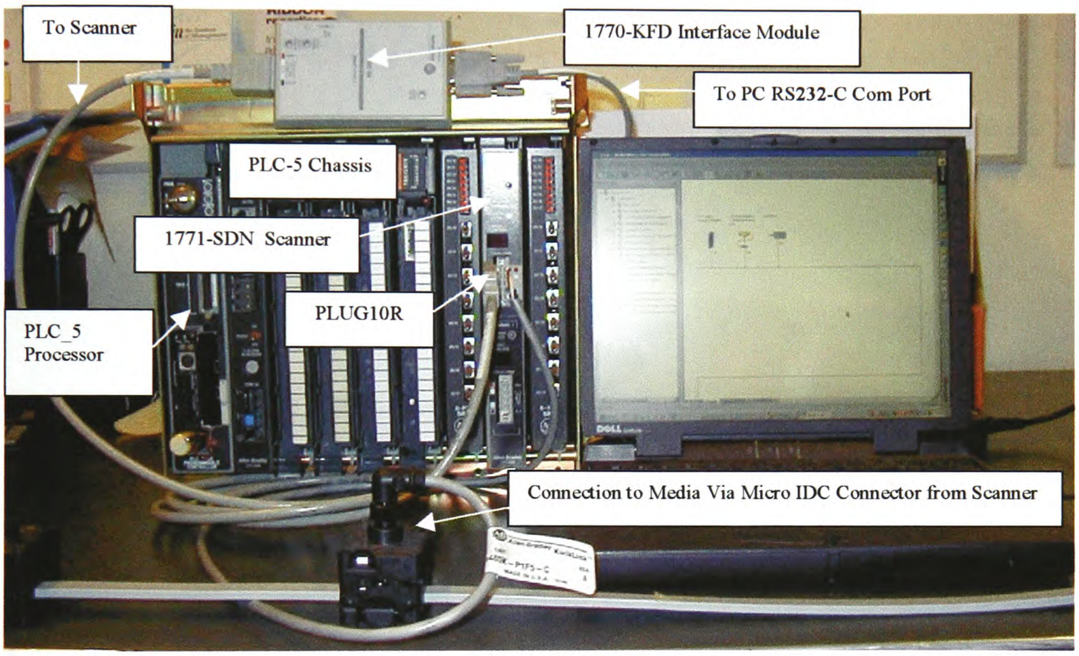


Figure 5-10 *Scanner to PC Via Interface*

1. Connect the RS-232 cable from the 1770-KFD to the serial port of the PC
2. Connect the RS-232 Cable to the 1770-KFD interface module
3. Connect the probe cable to the 1770-KFD Interface module
4. Connect the Micro to Conductor Cable to the PLUG10R

[iii] The address range is from 0-63

7. **Install demo version of RSNetworx for DeviceNet-** The RSNetWorx for DeviceNet software configures the parameters for DeviceNet devices from multiple vendors, troubleshoots the network and performs network diagnostics. The software is then downloaded from CD (supplied by Rockwell), to the PC.

8-10 Start RSLinx/Configure driver and browse online- The RSNetWorX communicates via RSLINX. Prior to configuring the communication driver the network and PLC rack holding the scanner was powered up. Having opened RSLinx (Figure 5-11) the next step was to select and configure a driver to communicate with the interface controller.

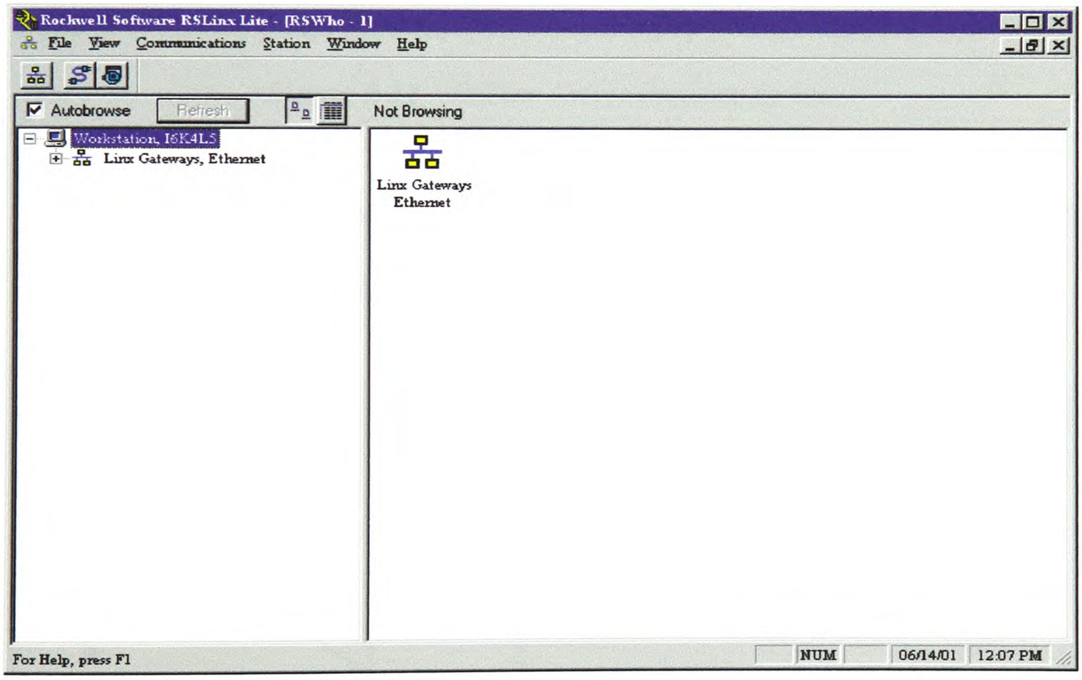


Figure 5-11 *RSLinx Initial Screen*

The appropriate driver was chosen by opening the communications pull down menu and selecting configure drivers (Allen-Bradley 1770-KFD). Having configured the port parameters i.e. com port, baud rate, node address and data rate the driver was initialized. Following this the display screen showed the driver as running (Figure 5-12).

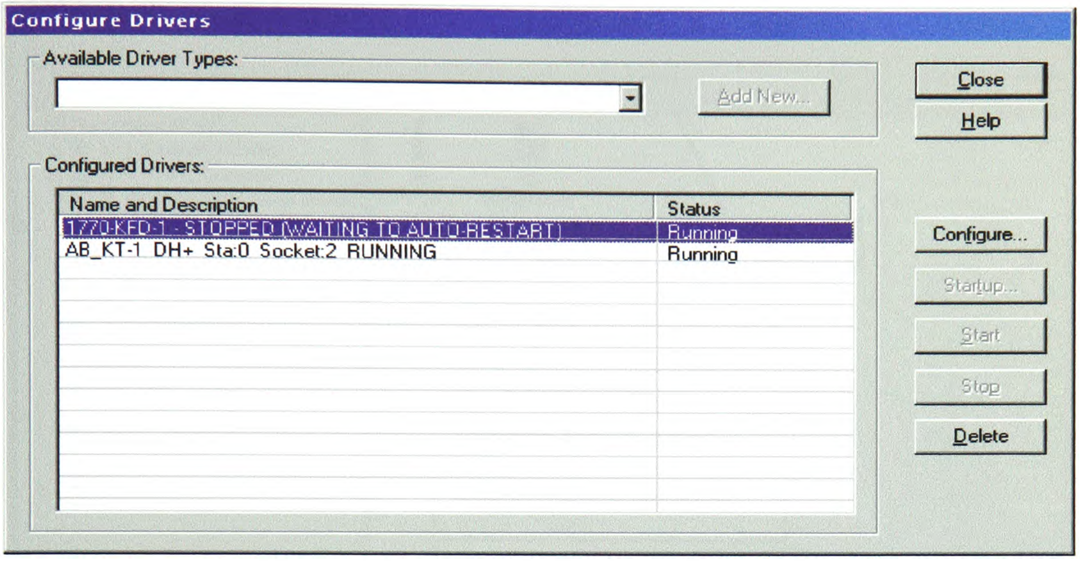


Figure 5-12 *RSLinx Driver Running Screen*

The initial WHO active start up screen now indicates that the 1770-KFD-1 interface module has been configured Figure 5-13.

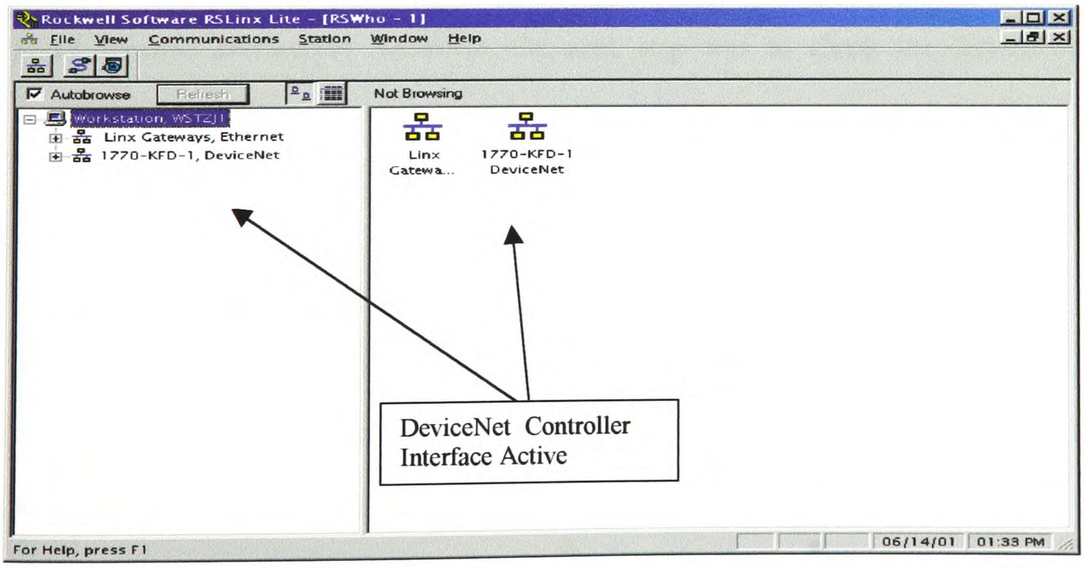


Figure 5-13 *RSLinx Network Running Screen*

By double clicking the 1770-KFD-1 DeviceNet Icon it was possible to browse the network (Figure 5-14).

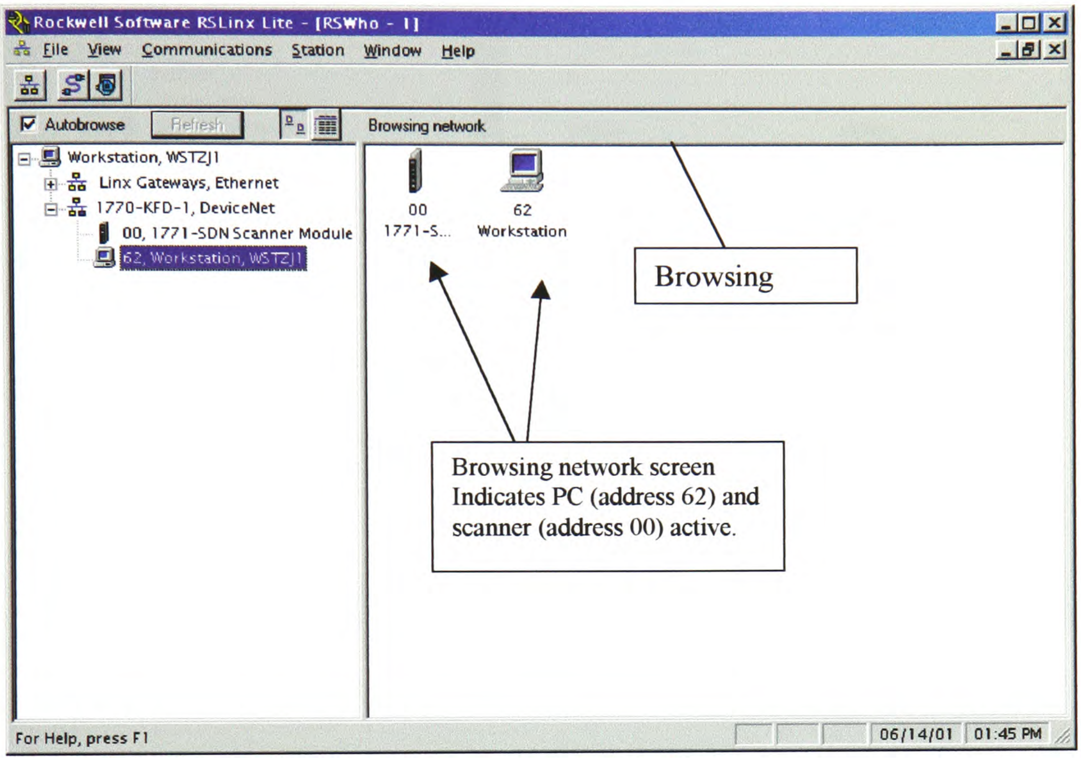


Figure 5-14 *RSLinx Network Browsing Screen*

11-12 Browse DeviceNet Network- the next step was to check the DeviceNet Network by:

- Minimizing RSLinx
- Starting RSNetWorx
- Go On Line by selecting the network on line Button on the tool Bar
- Select the 1770-KFD Interface for DeviceNet
- Select OK to Upload Network Data

After the RSNetWorx has polled the network a graphical display of the current status is displayed (Figure 5-15).

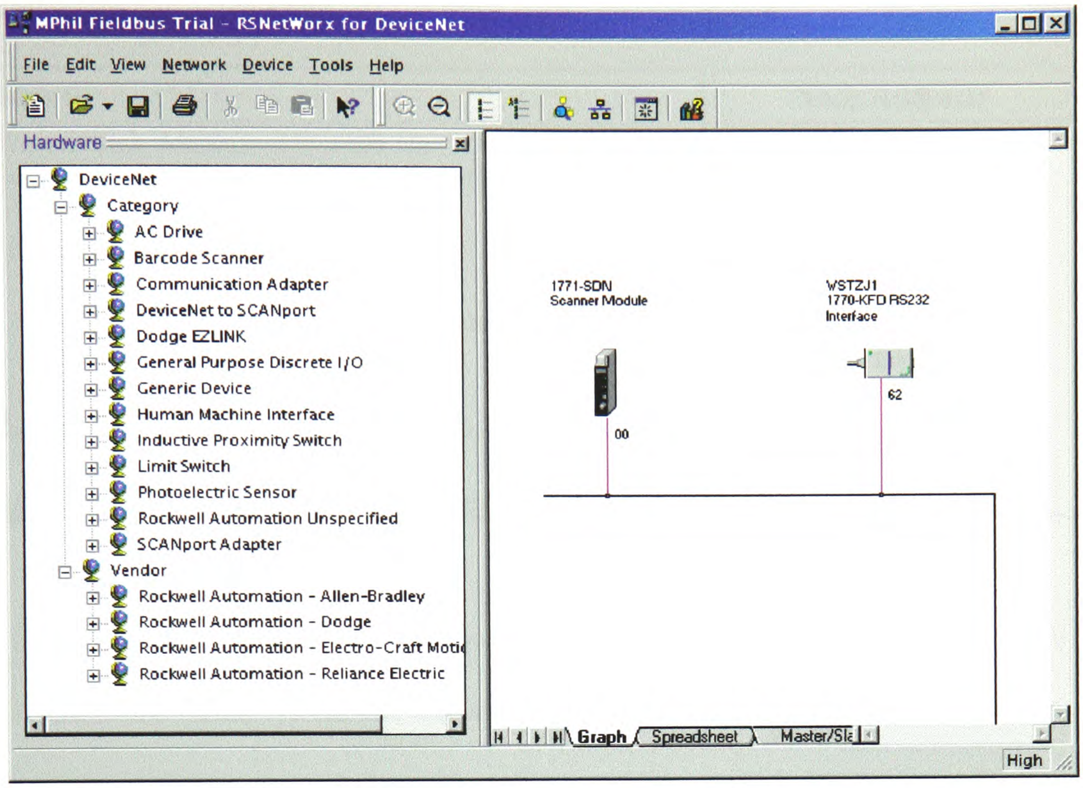


Figure 5-15 *RSNetWorx Browser Screen*

13-14 Commissioning Nodes- in some devices the node addresses can either be set manually using the rotary switches provided in this trial, these being the ArmorBlock MaXum (see Figure 5-9), CompactBlock I/O module (Figure 5-16), and the control tower stack light, or by using RSNetWorx via RSLinx over the network[iv]. The Inductive proximity and RightSight photoelectric Sensor are internally "switchless" so requiring the node address to be set by RSNetWorx software.

The devices found in Table 5-1 were connected and commissioned online using various techniques, thus thoroughly testing each of the methods:

[iv] The rotary switches must be set to 99 to enable the address to be set over the network. When the switches are set to 99 the devices are referred to as switchless.

Table 5-1 *Device Node Address Settings*

Device:	Node Address:
ArmorBlock MaXum I/O with the standard Proximity switch on input 1 (node address set with rotary switches	01
CompactBlock I/O (rotary switches set to 99)	02
Control tower stack light (node address set using rotary switches)	03
Inductive Proximity switch. (internal to 99)	04
RightSight Photoelectric sensor (internal to 99)	05

The ArmorBlock and control stack tower nodes were commissioned by attaching the devices to the media system and selecting the node address using the rotary switches. Once the addresses are set the nodes appear on the network browser screen. The screen refresh was used to update the screen and display the new nodes (Figure 5-17).

The remaining three devices were commissioned using the RSNetWorx software. The next section deals with the commissioning of the CompactBlock I/O device. The two remaining devices were commissioned using the same process.

The CompactBlock I/O (Figure 5-16) was connected to the network using the Micro connector to PLUG10R cable, as set out in the instruction manual.

Figure 5-16 *DeviceNet Compact Block I/O*

The node commissioning was completed by selecting/highlighting the Device (1791D Block I/O 8 Input/ 8 Output) from the hardware device menu, found under General Purpose discrete I/O Icon, then dragged over to the network view side (Figure 5-17).

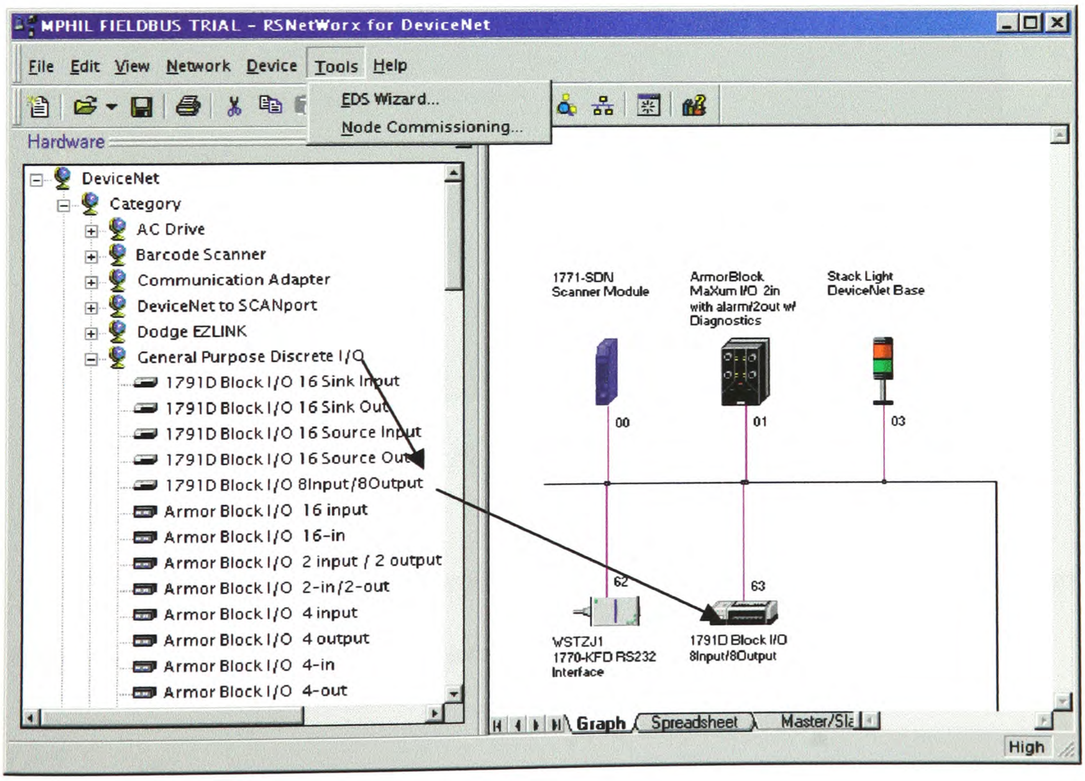


Figure 5-17 *Hardware Selection/Network Screen*

The next step was to select, from the tools menu, the node commissioning function button. Next click the browse button on the node commissioning screen. The application now shows a device selection screen similar to that in Figure 5-13. By selecting the controller interface the application software performs a Network WHO (update) of the current devices on the network. The 1791D Block appears with the default node address of 63. To select the correct node address click once on the CompactBlock I/O Icon, at which point the node commissioning screen reappeared showing the current node address and data rate of the compact I/O module. The Modules node address was set to 02 and the Baud rate at 125 Kb (Figure 5-18)

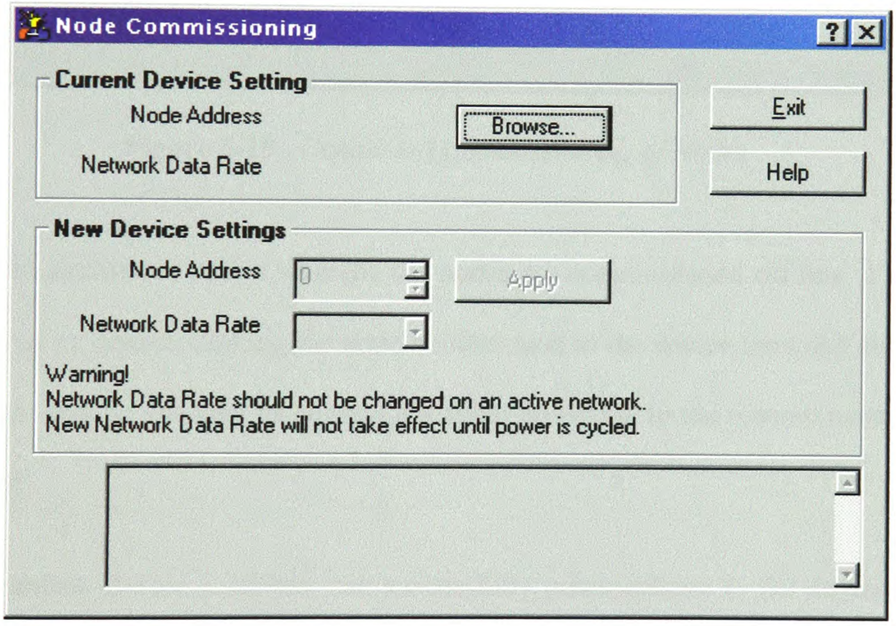


Figure 5-18 *Node Commissioning Window*

After carrying out the identical process for the remaining two devices the RSNetWorx view screen show the completed starter kit network (Figure 5-19).

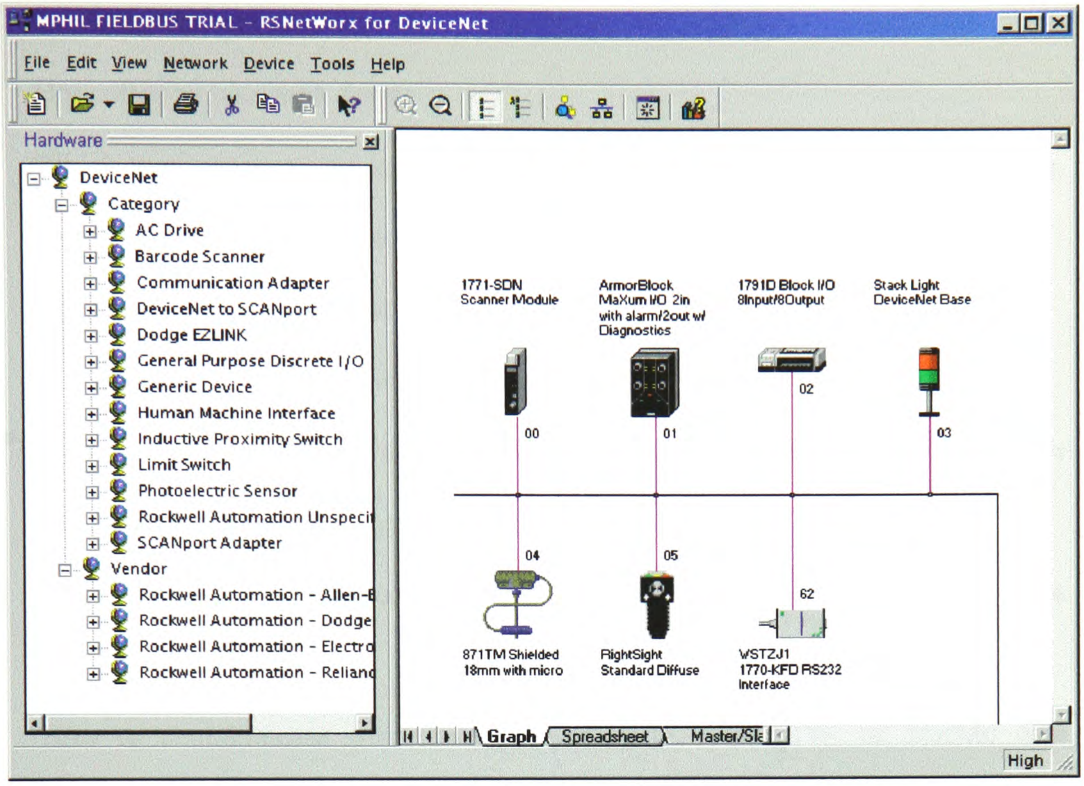


Figure 5-19 *Completed Commissioning of Nodes*

There is an alternative option whereby the nodes are commissioned off line. This can be achieved by double clicking the node number next to the device Icon and changing its address. Having changed its address a scanlist download to the scanner needs to be performed[v].

15-16 Scanlist- Before a scanner can successfully communicate to the devices on a DeviceNet network, it must first be configured. There are also module level parameters as well as the scanlist. The scanlist contains all the information required by the scanner to communicate with the devices. The scanner uses the information contained in the scanlist table (SLT) to determine:

[v] Step 15 explains in greater detail what a scanlist is and its function.

- What devices to scan
- How often to scan each device
- Which memory locations in the device contain the desired input or output data; including the size of the data
- The number of bytes to send or transmit (Tx size)
- The number of bytes to receive (Rx size)
- How to communicate with each device (strobed, polled, change of state, cyclic, or any valid combination of these parameters)
- Where to map input data and output data to enable the processor to read and write it
- How to communicate with the processor (DIO, BTR/BTW, or M1/M0 data transfer)

Most of these data can be automatically configured using the automapping feature of RSNetWorx (which was the case with the previous steps).

The next section demonstrates how to:

1) Build a scanlist.
2) Map the network inputs and outputs
3) Review the scanner summary window
4) Download the software configuration to the scanner
5) Edit the I/O parameters of the Inductive proximity switch

1-4. To build a scanlist select File/New and go online to display the network. Double click the scanner (node 00) on the DeviceNet network to display the properties dialogue box (Figure 5-20).

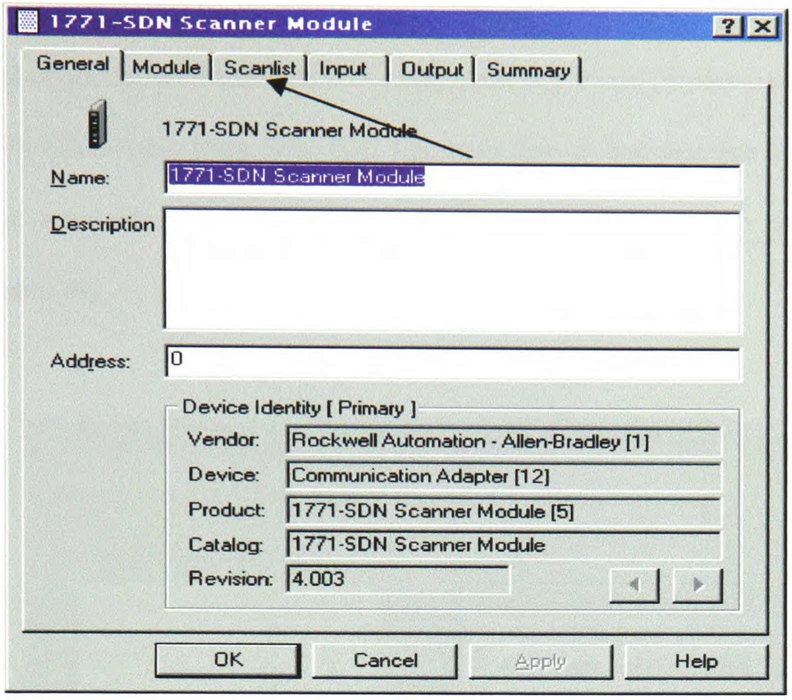


Figure 5-20 *1771 Scanner Properties Screen*

Select the scanlist function to bring up the scanlist window Figure 5-21.

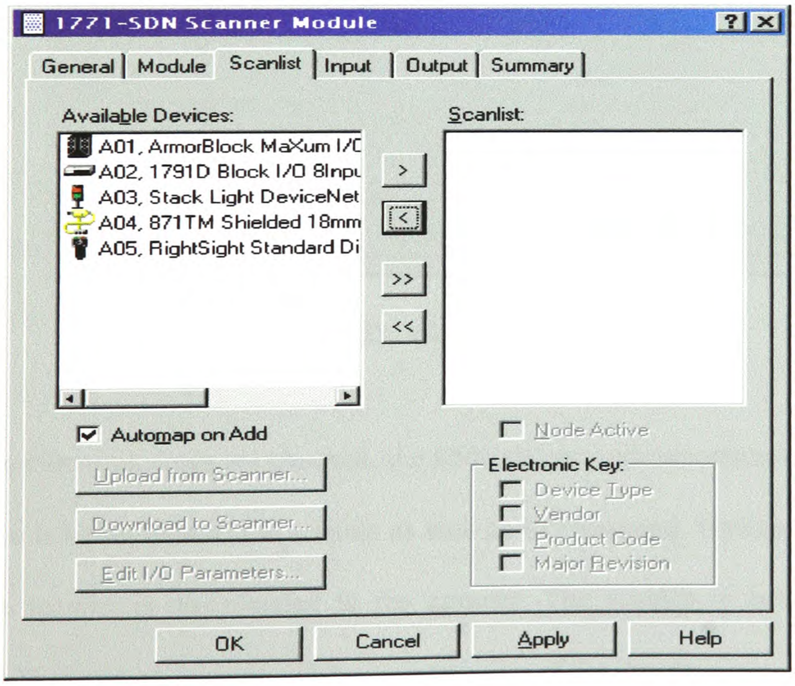


Figure 5-21 *RSNetWorx Scanlist Window*

The Automap was checked to ensure that once the devices have been added to the scanlist and downloaded the RSNetWorx automatically maps the devices based on the current EDS (Electronic Data File) file. The next step in building the scanlist was to add all the available devices to the scanlist. Figure 5-22 shows the completed compiled scan list.

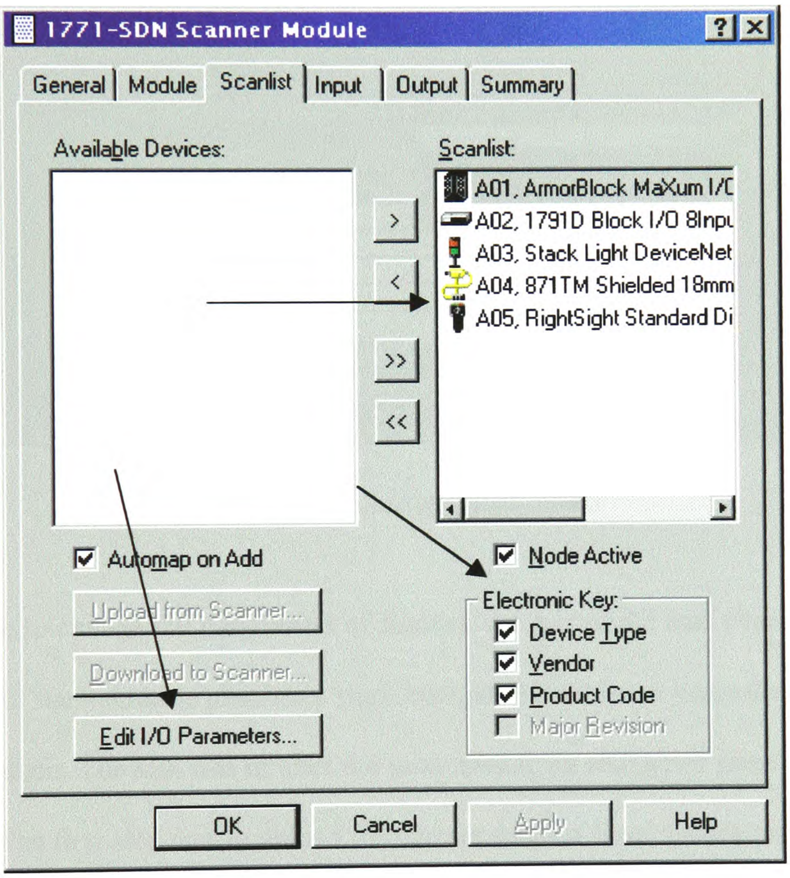


Figure 5-22 *Compiled Scanlist*

When the electronic keys are checked, the RSNetWorx will remember what version of the device is being read to the scanlist as well as I/O mapping. Having completed the steps the scanlist is downloaded to the scanner. The scanlist is now automapped, Figure 5-23 shows an example of the automapping of the inputs.

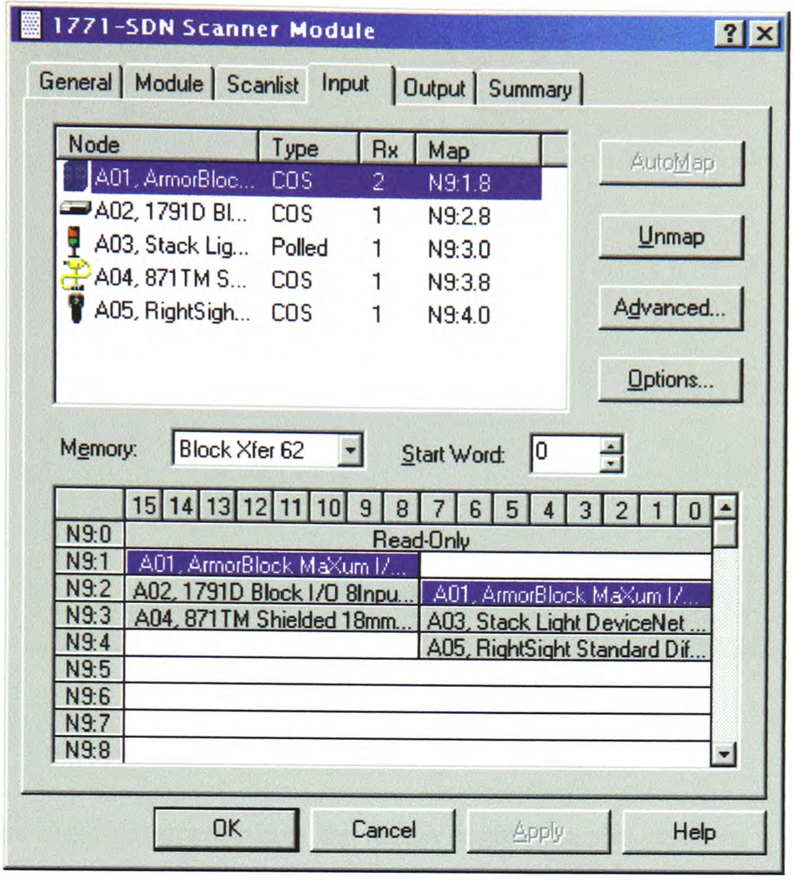


Figure 5-23 *Automapped Inputs*

It is possible to change the parameters of devices. As part of the trial alterations to the parameters of the inductive proximity were instigated in order to study the complexity of this operation. The aim was to alter the proximity from change of state/cyclic mode to strobed. The first step was to upload the current scanlist from the scanner. With this stage completed the next stage was to select the inductive proximity from the scanlist and click the edit I/O parameters button (see Figure 5-22). With this completed it was then possibles to first uncheck the change of state/cyclic box and then check the strobed box (Figure 5-24).

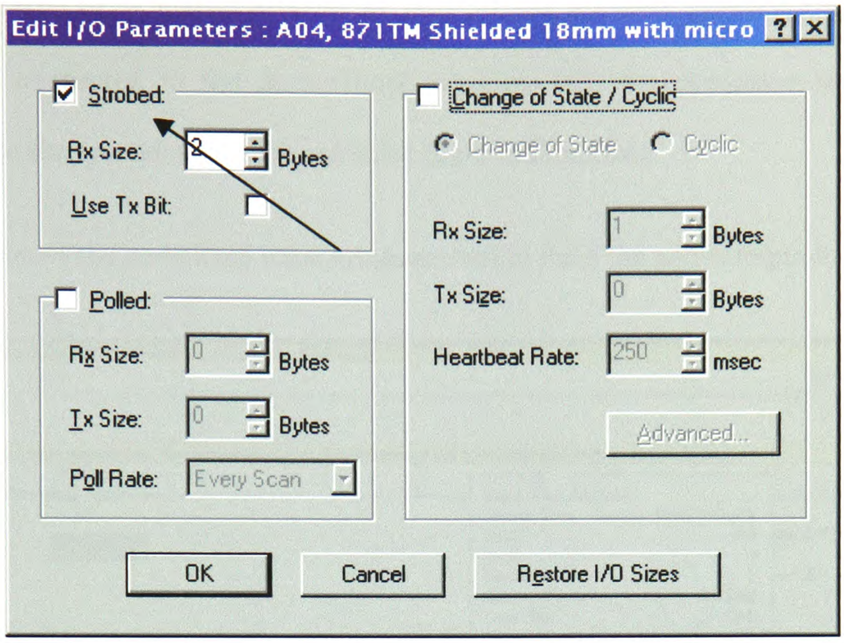


Figure 5-24 *Edit I/O Parameter Screen*

17-18 ladder logic programming- the ladder logic program provides a way for the devices to communicate with the scanner and to perform basic functions or react to a trigger: For this trial a ladder logic program was configured using Rockwell RSLogix 5 Revision 3.0 application software to produce responses when:

- When an object is placed in front of the RightSight Photoelectric sensor the processor (the location of the ladder logic) tells the scanner that the green Control Tower Stack light needs to illuminate.

- When a metal object is placed in front of the inductive proximity switch an analogue value is sent to the processor. Depending on the object's distance from the inductive proximity switch the ladder logic sends a message to the scanner to turn on the respective CompactBlock outputs.

- When an objgect is placed directly in front of the standard proximity switch, which is connected to the ArmorBlock MaXum I/O, the processor sends a message to the scanner to tell the red stack Light to illuminate.

Figure 5-25 shows the completed logic program used to fulfil the above requirements.

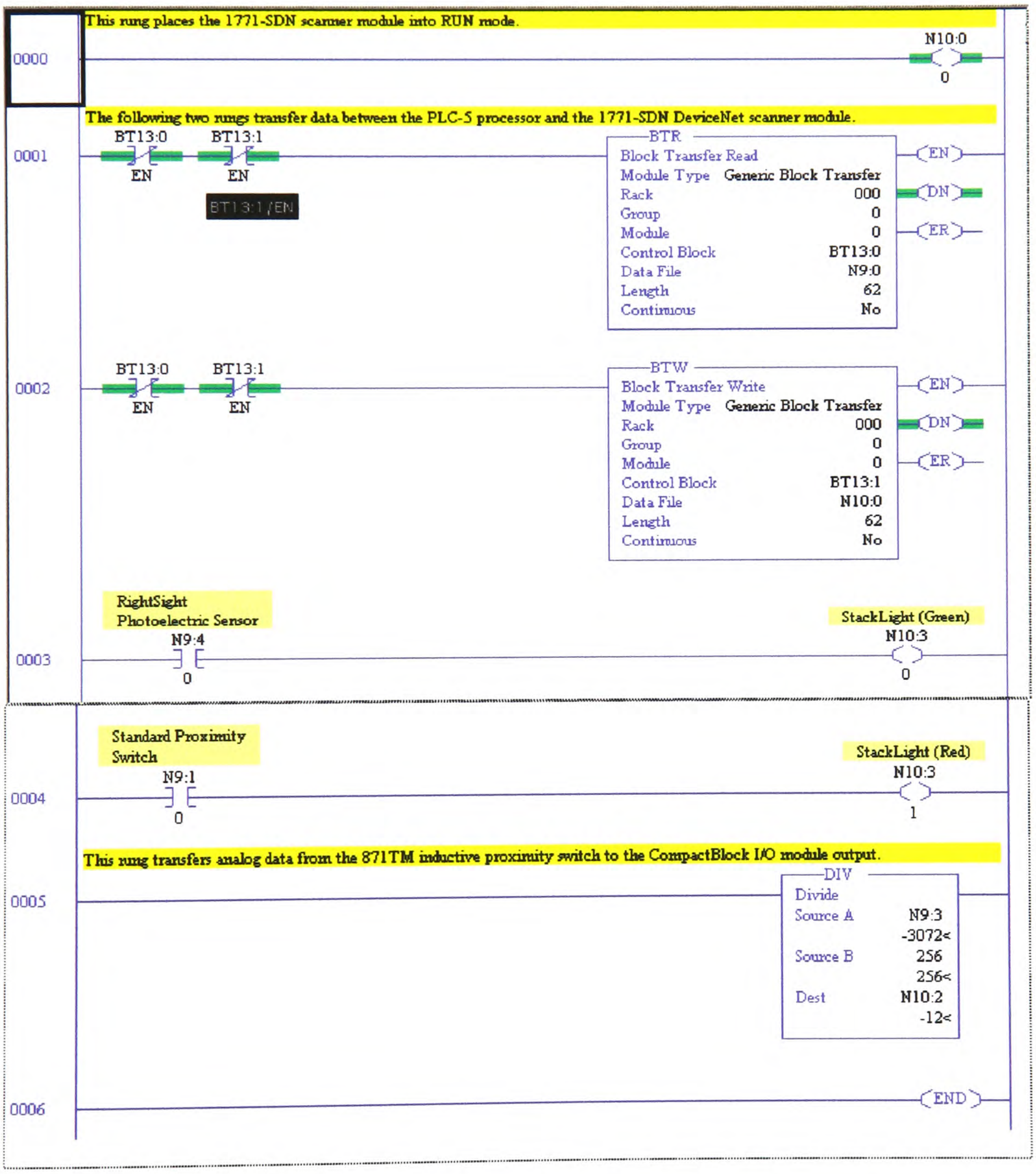


Figure 5-25 *Ladder Logic Program*

19. Experimentation with devices- experimentation was carried out by:

1. Placing an object in front of the RightSight photoelectric sensor and confirming the illumination of the green Control Tower stack light. The data was also viewed using the mapping tables and monitoring the inputs and outputs.

2. Placing a metal object flush against the standard proximity switch and observing the illumination of the red light on the tower stack. The data was also viewed using the monitoring facility of the RSLogix Figure 5-26.

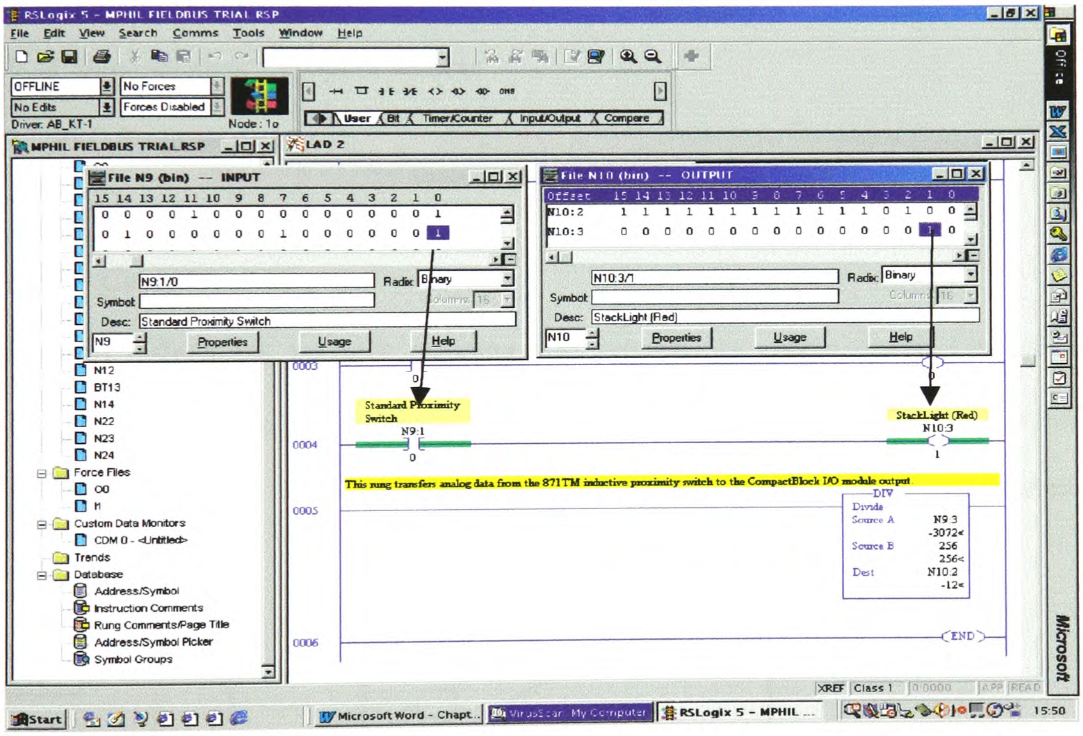


Figure 5-26 *Ladder Logic Data Monitoring Screen*

3. Placing a metal object flush against the inductive Proximity switch. Confirmation is confirmed by the illumination of the low byte of the I/O output LED's. The metal object was move slowly away whilst observing the LED's and monitoring the input table.

4. The above procedure was carried out for the remaining devices and observations made using both the ladder logic and mapping tables.

5.2 FIELD TRIAL

Having assessed the ease of use by constructing the starter kit using the 19 steps contained in the starter kit instruction manual, the next stage was to install the network on the converting line. This was necessary in order to compare and evaluate the reliability of the network in the field. The installation process was carried out in the following stages.

1. Cable Planning/ Layout of devices
2. PLC Program design
3. Installation

5.2.1 Cable Planning

Prior to installation, network planning was required to ensure Trunk Line (Bus Length), drop length and power requirements were within the recommended specification. Figure 5-27 gives an overview of the DeviceNet network cable system and its terminology.

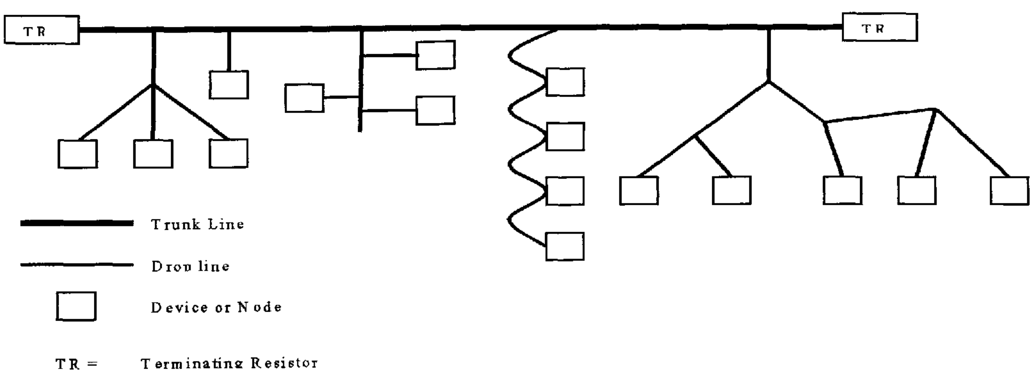


Figure 5-27 *DeviceNet Cable System*

The maximum bus length depends on the type of cable used and data rates required

Table 5-2 shows the relationship between the two.

Table 5-2 *Maximum Trunk Line Distances*[vi]

Data Rate	Maximum Distance (Flat Cable)	MAXIMUM DISTANCE (Thick Cable)	MAXIMUM DISTANCE (Thin Cable)
125K bit/s	420m (1378 ft)	500m (1640 ft)	100m (328 ft)
250K bit/s	200m (656 ft)	250m (820 ft)	100m (328 ft)
500K bit/s	75m (246 ft)	100m (328 ft)	100m (328 ft)

For this trial Class 1 Flat cable with a maximum rating of 8A was used. An example of the ratio of current to trunk line distance for a flat cable with the power supply placed at the end segment is shown below Figure 5-28.

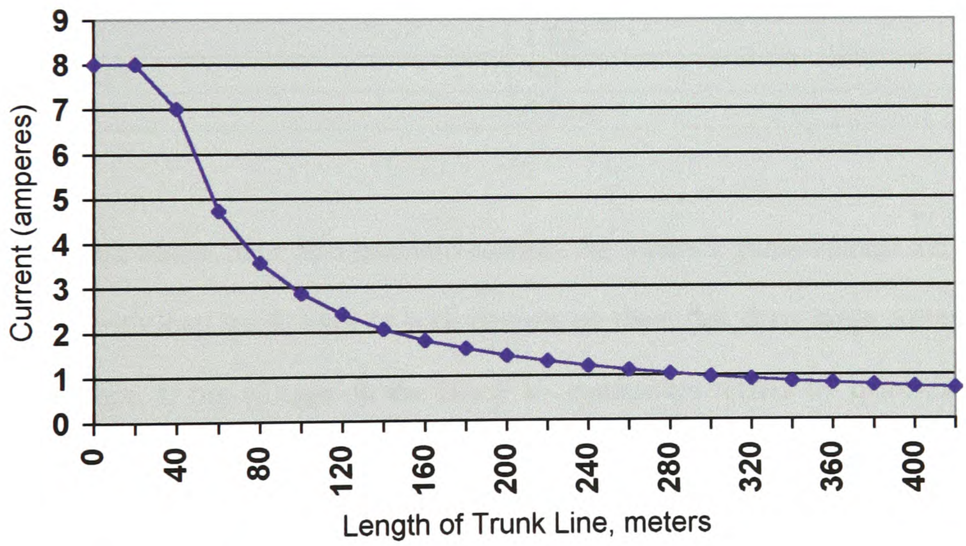


Figure 5-28 *Ratio of Current to Trunk Line Distance*

The accumulative drop length is also governed by the data rate (Table 5-3).

[vi] The maximum cable distance is not necessarily the trunk length only. It is the maximum distance between any two devices.

Table 5-3 *Relationship of Data Rate to Cumulative Drop Line Length*

Data Rate	Cumulative Drop Line Length
125K bit/s	156m (512ft)
250K bit/s	78m (256ft)
500K bit/s	39m (128ft)

The maximum distance allowed between a node and trunk line is 6 meters. The maximum allowable current from drop lines can be calculated using the following formula, I= 15/L or I=4.57/L, where L is the drop line length in feet and meters respectively (Table 5-4).

Table 5-4 *Relationship between Drop Line Length and Allowable Current*

Drop Line Length	Allowable Current
1.5m (5ft)	3A
2m (6.6ft)	2A
3m (10ft)	1.5A
4.5m (15ft)	1A
6m (20ft)	0.75A

The network design must also take into account the common mode voltage difficulties expected with long trunk lines or with devices on them that draw large currents at a long distance. If the voltage on the Black V- conductors differs by more than 4.65 volts from one point on the network to another, communication problems can occur.

Another factor to be considered is if the voltage between the black V- conductor and the red V+ conductor falls below 15 Volts, then the common mode Voltage could adversely effect network communications. To assist in this planning process a software package (DeviceNet assistance developed by Rockwell) and the Planning and Installation Manual provided with the starter kit was used. The cable layout shown in Figure 5-29 was designed in such a way that all components supplied with the starter kit were fully utilised.

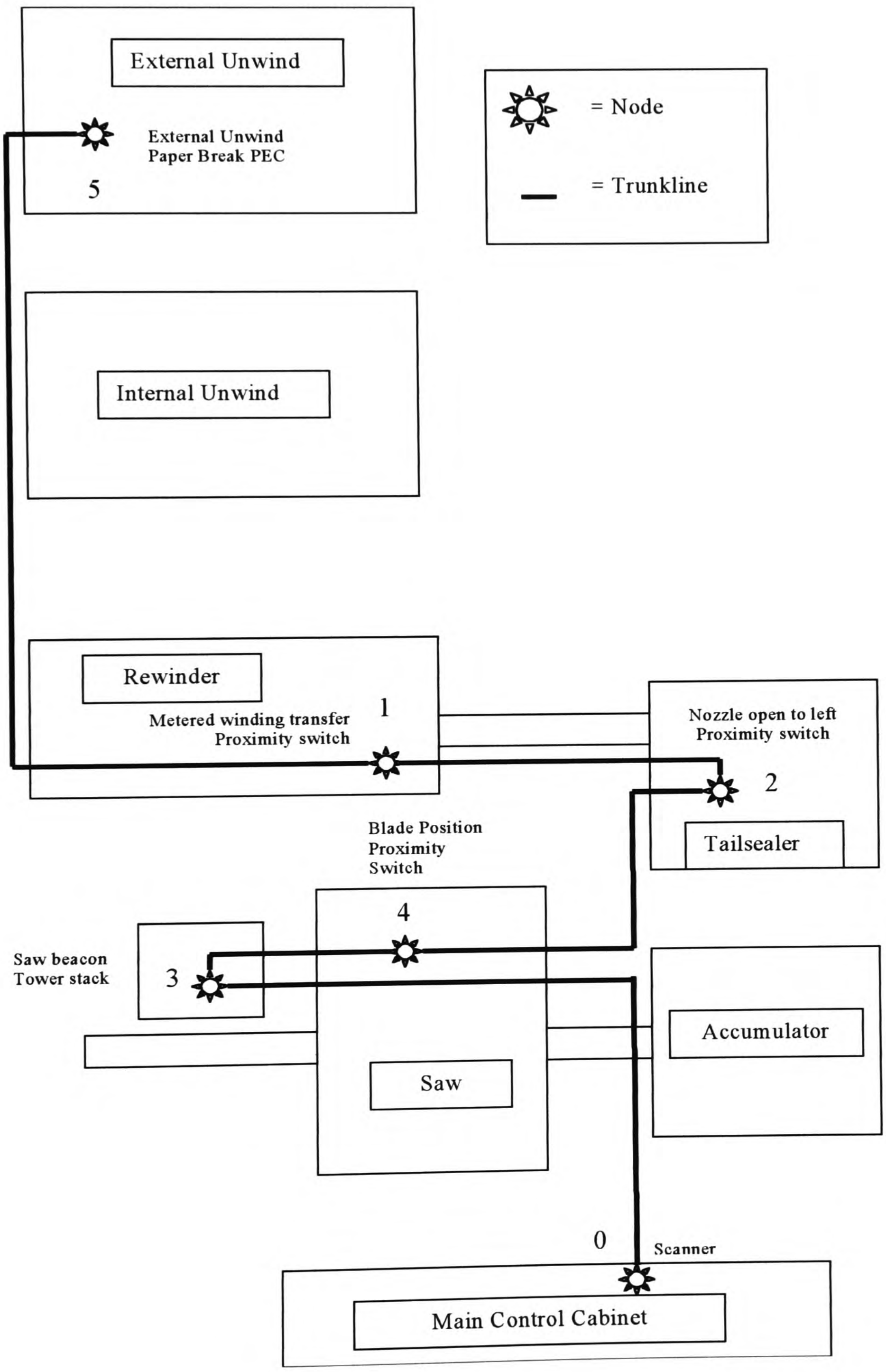


Figure 5-29 *Line 10 DeviceNet Network Cable Layout*

The distances between nodes (see Figure 5-30) were measured assuming the network trunk line cable was run in parallel with the existing proprietary Remote I/O network cables inside the trunking. Between the Rewinder and Unwind stand the DeviceNet trunk line cable was run inside the motor cable trunking in order to test its immunity to noise. To gain a direct comparison the devices, where possible, were placed in parallel to existing devices. After inputting these data into the DeviceNet Assistance it became evident that extra power supplies would not be required and that zero problems had been experienced with the allowable current through the trunk and drop lines. The software package indicated there were no problems with voltage drop, trunk line length and accumulative drop line length. The software also indicates the maximum data rate that maybe used (Figure 5-30).

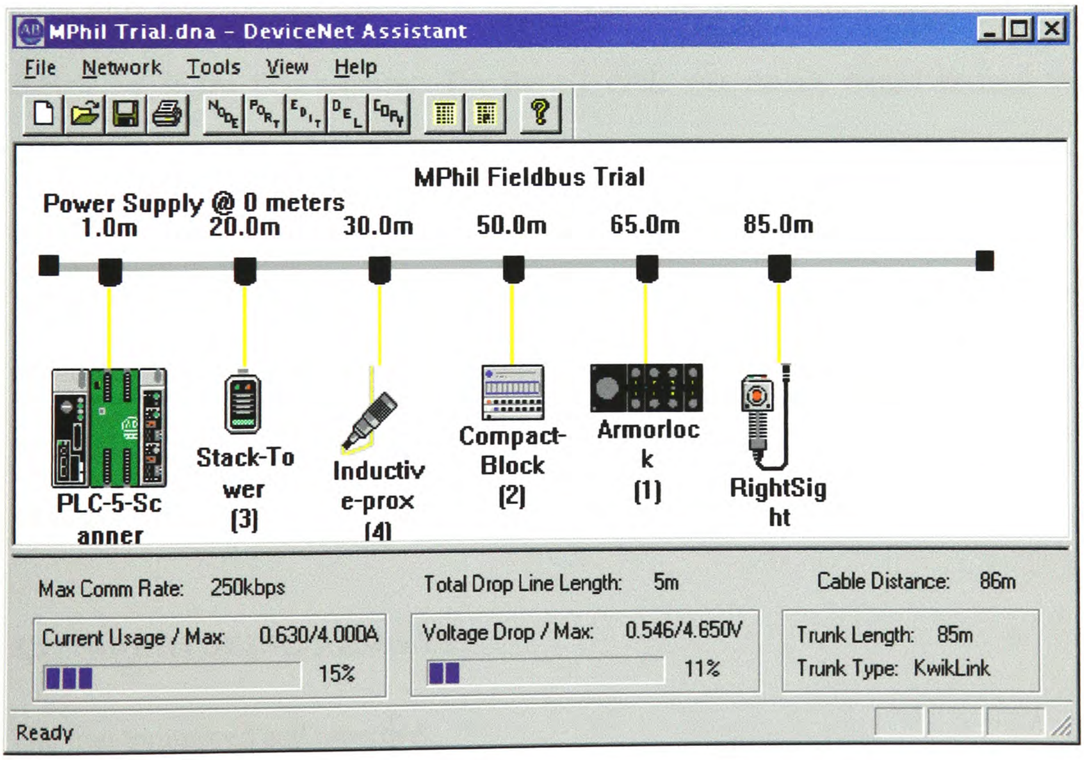


Figure 5-30 *DeviceNet Assistant Network Layout*

The cable installation was designed within the recommended guidelines. The next phase was to construct a PLC Program to capture the actions of the Devices on the network and to compare the results with the existing device performance of the existing network.

5.2.2 Constructing a PLC Program

The main part of the PLC program used to test and monitor inputs and outputs when constructing the kit was modified to enable a direct comparison with existing devices on the network. The modified program was then downloaded into line 10 PLC-5 processor.

5.2.3 Installation

The installation was carried out by inserting the scanner into the spare slot on the main PLC chassis. The network power supply was also located within the PLC cubicle i.e. in the first segment. The flat C1 cable was mainly routed through the dedicated low voltage trunking, only deviating from this when running from the rewinder to the external unwinder. Here, the network cable was placed in the high/medium voltage trunking which includes the motor cables. Where possible, the new devices were fitted as close as possible to the existing devices. Air jets de;iberatly were not fitted to Node 5 RightSight sensor. Air jets are designed to keep the lens clear of the build up of dust.

5.3 MONITORING/RESULTS

The trial monitored and recorded:

- Construction of the starter kit prior to the machine trial
    - Clarity of instruction

  - Ease of Use
- Field trial
  - Commissioning
  - Reliability
    - Network
    - Devices
  - Accuracy of data from devices
  - Ease of use

The findings of the trail and case studies were compared, resulting in a recommendation being issued.

The trial was carried out over a 3 month period with results, where necessary, being recorded on a weekly basis.

5.3.1 Monitoring the Construction of Starter the Kit

The process of constructing the starter kit was monitored and recorded throughout the 19 steps. The next section looks at the results in terms of clarity of instruction, accuracy and ease of use of the network and its components.

Step 1 identifying the parts and organizing them as per instructions presented few problems.

One of the main problems found in steps 2-4, assembling the KwikLink media system, was that all but one of the first latch stage of the IDC connector failed to work, thus not allowing easy positioning and alignment of the IDC connector. Another problem experienced was not knowing the correct depth to screw the IDC screws to ensure the blades pierce the cable. Initial attempts took approximately 3 minutes to complete, which decreased to 1 minute with familiarity.

Step 5-6, setting up the 1771-SDN Scanner dipswitches and connecting the interface cable, presented no technical problems. Although there was a minor concern, concerning stiffness of the probe cable when moving the RS232 interface adapter. This put strain on the plug connections going into the PLUG10R socket.

Step 7 - RSLinx had been installed within the laptop prior to the field trial, it was not necessary to re-install. Previous experiences in installing the RSlinx had given the author some cause for concern. The installation of RSNetWorx took place without problems.

Step 8-12 working with RSLinx software to Configure the DeviceNet driver was completed without any problem. The author has sound knowledge of RSLinx and as such easily navigated through the various menus[vii].

Steps 13-14 commissioning of the Nodes presented no particular technical problems but possibly contained too many stages. A small but annoying problem concerned the constant need to refresh the screen every time a device was commissioned in order to display the current network.

Step 15 using the instructions for a PLC5 processor, the scanlist was setup with little problem.

Step 16 the I/O parameters were adjusted as per instructions set out in the manual.

[vii] As the RSLinks is windows based a person with limited experience should have little difficulty in navigating it.

Steps 17-19 the example ladder logic was installed into the PLC5-30 processor. The network was then placed in run mode where it functioned without requiring changes to the program[viii].

5.3.2 Installation and Commissioning

The cable installation times of the DeviceNet C1 cable were on the whole comparable with that of Allen Bradley's Remote I/O network, the main differences being that a 24v supply cable was not required to be run separately in this instance. However, other applications may require devices to be separately powered or segments may require additional power requirements. A definite limiting factor was discovered when using the C1 flat cable. Its inflexibility makes it awkward to manipulate around corners. This problem may be reduced/eliminated by using the round thick/thin DeviceNet network cable. Cleating the cable also presents a problem as all cleats are designed for round cables.

The connection times of the IDC Connectors decreased from 3 minutes when first connecting the node off-line to approximately 1minute when commissioning on the actual machine.

The planning of the cabling proved to be adequate - no voltage or current problems were experienced throughout the trial.

The network was commissioned without any problems such as connecting devices to the wrong Nodes, poor connections etc.

[viii] The time taken to construct the starter kit in its entirety from steps 1-19 was 6 hrs

5.3.3 Reliability of Network and Devices

The network scanner was monitored once a week for any indications of errors in either the network or the devices. There were NO faults recorded. From these results it was ascertained that running DeviceNet media cable next to high voltage cables (415v) did not cause any reliability problems due to electrical noise.

5.3.4 Monitoring/Results Accuracy of Data

Two counters per device were programmed for both the existing sensor and the DeviceNet sensor in parallel with it. The aim was to compare any differences in counts due to scan timing, environment etc. The counters were checked once a week. The results showed there to be no difference between the proximity switches. The RightSight Photocell flagged up a problem after 10 days of running. This was found to be due to dust on the lens, which caused the input signal to become unstable and fall below both margins[ix] 1 and 2 fixed at 0.7-1.5 and 0.7-2.0 of the input signal level respectively. An air blower was then fitted which eradicated the problem throughout the remaining period of the trial. No other alarms were experienced from any of the devices on trial.

5.3.5 Ease of Use

The hardware network components were easy to assemble using the one way fittings, so guaranteeing correct building of parts i.e. IDC connectors. The main hardware problem was the manipulation of the Flat Network cable which was inflexible (as previously mentioned). The software was windows based and so easy to navigate. The diagnostics proved to be easy to interpret.

[ix] Margin is defined as a measurement of light reaching the photodetector over the minimum light required to operate the sensor's amplifier by crossing its threshold level. The calculation is expressed as a whole ratio. In equation form: marin = light reaching the reciever/ Amplifier light.

The plant maintenance technicians were given a half-day seminar on DeviceNet and RSNetWorx. The feedback from the seminar was positive in that the technicians believed it to be an advantage over the proprietary network. The proprietary network has no diagnostics other than simple adapter fault lights and processor configuration data. One week after the seminar each of the technicians was asked to find predetermined faults on the network. The faults comprised an open circuit of the network, wrong device, and power supply failure. The technicians succeeded in finding all the faults, and all commented on the user friendliness of the diagnostics and the time saving in fault finding.

5.4 CONCLUSION

The overall clarity of the instruction manual was excellent and without errors. It became apparent when constructing the starter kit that prior knowledge of the Allen Bradley style of software and PLC programming knowledge would be beneficial to fully understand each step. Whilst there were no errors in the manual there was one omission, the minimum processor requirement. This presented a problem when initially trying to use a PLC5- 15 as it did not support DeviceNet. A PLC5-30 was tried and found to be adequate. Overall setting-up and ease of construction was very good. The ease of use was adequately demonstrated by the short time taken to construct the kit by personnel who were without any formal training on DeviceNet. The design of the network cabling was made easier by the use of DeviceNet assistance. This software package was not supplied with the starter kit. Without it, one must conclude that using solely the guides set out in the planning manual accompanying the starter kit, and having to source all the current requirements, would take up valuable time and could lead to inaccuracies. In the opinion of the author the

DeviceNet assistant should be part of the RSNetWorx software. If this was the case it would be possible to both design and commission using just one package.

The field trial on the machine matched the interviewees' reports, mentioned in Chapter 5, in terms of both being easy to use, for construction and design by project Engineers and for fault finding by the maintenance technicians. Although this was only a 3-month trail the reliability was as anticipated, with no faults experienced with either the software or hardware. Another benefit from a process/maintenance point of view is the ability through the EDS file to ensure that when components are replaced, they are replaced with the correct type, thus guaranteeing process quality.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

This research demonstrates, and indeed reinforces, that fieldbus is a practical and effective technology for delivering real benefits to the end user as well as being economically viable when correctly selected for a particular application.

This study concentrated on the selection of an optimum fieldbus for the paper converting process and includes several techniques to help in the execution of the selection process. Among these techniques is a two dimensional decision making methodology, a potential risk analysis, cost comparison software tool and a fieldbus trial.

From the onset of this research it became evident there had been few in-depth investigations into the methodology of selecting fieldbus for a particular application. What little literature there was came in the form of guidance notes, which concentrated mainly on the technical/performance criteria and provided no method of evaluation or risk analysis. It is hoped this study goes some way to addressing these omissions.

From the many techniques available it was decided that Kepner Tregoe provided the better all round performance. It was selected for its systematic, informed balanced and non biased, two dimensional approach to decision making. Six alternative fieldbuses were selected for evaluation: - DeviceNet, SDS, Profibus DP, LonWorks, Interbus-S, and Seriplex. The criteria used in the evaluation were derived from the findings in

Chapter 4 and the author's understanding of the converting process. These criteria were split into two main categories;

1) Technical Characteristics looking at criteria such as the physical characteristics, transport mechanisms etc.

2) Strategic issues such as cost, features and technical/development support.

The evaluation process emphasized the most likely optimum fieldbus for use in the converting process would be DeviceNet. The methodology itself proved very easy to use, whilst the results correlated closely to those found by Venture Development Corporation. Due to the fuzzy nature of some of the criteria it is possible that a few findings may be disputed by some commentators. Unfortunately there are no hard quantifiable measurements to point to an indisputable answer; for example usability is reliant on interviews and application experiences of others – both are subjective and by no means an exact science. Another drawback with the methodology was that it is open to miss use - because the process itself is so subjective in setting the importance of criteria and the evaluation process leaves itself wide open to individuals who may have particular preferences and want to manipulate the outcome.

To highlight any potential adverse consequences that may affect the selection of DeviceNet, a potential risk analysis was carried out as part of the Kepner Tregoe process. Five factors were produced which may give rise for concern and thus influence the final decision on the selected fieldbus. The five factors are:

1. ***Rockwell being merged or taken over*** - the possibility that Rockwell would merge or be taken over by a rival company was dismissed by the author, believing that

the newly formed company would still continue to play a major role in supporting the Open DeviceNet Vendors Association.

2. ***The incorrect selection due to either lack of or missing information*** - the lack of information on comparative costing against current networks used within the paper converting process placed a risk of failing to meet one of the major criteria of low overall cost. To eliminate the risk, a cost comparison software tool was used to study the comparative costing of installing a system using Direct (Centralised) I/O, Flex I/O networked to Allen-Bradley's proprietary Remote I/O network and DeviceNet. The findings from the study highlighted several factors that could influence the overall installation cost of a network these are; distance, incremental cost of the device, labour time and overheads. Over the two scenarios the cost analysis tool highlighted on average a saving of 78.5% on installed cost using DeviceNet over flex I/O and Direct when using conventional discrete I/O devices. However when a premium cost greater than £15.00 per device is included in the calculation DeviceNet becomes more expensive than both flex I/O and Direct (Figure 5-9). Vendors are reluctant to publish a factor, which includes a premium for devices. One suspects the reason for this is that it may have an adverse affect on the company sales.

There were some reservations as to the simplicity of the cost analysis tool because it does not take into account any of the following areas:

- Overheads
- Savings on drawing and design time
- Savings over life cycle due to greater uptime
- Savings due to greater diagnostic features of DeviceNet
- Cost of software and diagnostic tools

Whilst these factors were not taken into account it is the authors belief that had they been included there would have been an even greater saving with DeviceNet over that calculated in Chapter 5 section 5.7.

The missing information related to one criterion in particular – backward compatibility, it was decided, as this was a very low Want criterion, omitting the criterion would not affect the outcome. This may not always be the case and as such careful consideration should be given, prior to selecting the alternatives, that all information is available.

3-4. ***Reliability of Fieldbus and accuracy of data*** - in order to assess the reliability of DeviceNet and verify the accuracy of the data used in the selection, a fieldbus trial was carried out.

The field trial was set-up using Rockwell's DeviceNet starter kit. The trial consisted of two parts. The first part involved constructing the starter kit using the nineteen steps contained in the "Getting Started" manual thus assessing the ease of use of the network and the clarity of instructions. The second part of the trial involved designing and installing the network onto a converting line which would allow one to gain an insight into the benefits of the network from the design stage to the overall reliability.

The findings of the trial mirrored those obtained from the interviews used in the evaluation process in terms of ease of use and reliability. The trial also highlighted the stability of the fieldbus and its potential to save on installation and design time. Several niggling negative factors were discovered during the trial, for instance the in-flexibility of the media used i.e. KwikLink flat cable, latch problems on the IDC connectors, cleating and some issues surrounding the software. Apart from these the overall DeviceNet network performance was as anticipated.

5. ***Future direction of fieldbus- after considering the findings from Chapter 2*** – with the imminent introduction of Ethernet/IP, it was concluded this risk is outweighed in both the short and medium term by the cost effectiveness of DeviceNet.

From the onset the major objectives of this study were to:

- Select the optimum Device level fieldbus for the paper converting industry.
- To use a software tool to assess the main benefits of fieldbus
- To carryout a small-scale trial to facilitate the evaluation of risk with a newly selected product.
- To make recommendations either to implement open fieldbus technology or remain with the status quo

The final outcome was that all four major objectives were achieved in full

6.1 RECOMMENDATIONS

Whilst the author's recommendation is for DeviceNet to supersede the existing proprietary network on all new and retrofit projects, it is advisable that the following precautions and recommendations be adhered too:

1. Adequate training to be given to all appropriate personnel prior to the first DeviceNet installation.

2. Approved integrators to be used to design, install and commission the network.

3. In order to guarantee interoperability, or until there is a common worldwide standard or tests are carried out on devices prior to purchase (see section 6.2), only Rockwell devices should be purchased.

4. No intelligent devices to be used until such time that the management data system is upgraded to cope with the extra information required and to be of benefit to the company.

5. OEM's supplying Georgia Pacific to be informed that DeviceNet is now company standard and insist it is adhered too.

6.2 FURTHER WORK

More work is required to ensure Georgia Pacific obtains the greatest benefit from DeviceNet. The following work is required to be carried out:

1. The testing of components for interoperability. Due to financial constraints and the number of products available this fieldbus trial did not include research into interoperability by the testing of devices from various manufacturers.

2. The integration of information from the intelligent devices on DeviceNet into SAP for maintenance, and management data.

3. To access the network devices and data through the internet

4. To refine the cost analysis tool to include such items as overheads, savings on drawing time and life cycle uptime to allow the calculation of the pay back period when justifying capital investment.

REFERENCES

Aimax On-Line. *SMAR fieldbus Tutorial.* http://www.ta-eng.com/industry/mforum. 4th January 2001.

Angus, H. 1999. *Protocol Wars II or Olive Branch.* Maufacturing Automation Magazine, http:/www.automationmag.com, 31st January 2001.

Arc Advisory Group. 1998. *Field Networks Redefine Automation System Architecture.* http:/www.arcweb.com/arcsite/arc_news, 31st January 2001.

Ball, K. 1997. PLC I/O Systems. *News, Views, and Networks.* Control Engineering Magazine, pp. 81-86.

Barker, A. 2000. *How to be a Better Decision maker.* London, The industrial society, p10.

Bazany, R. 1997. *Choosing a Control Network.* Plant Engineering Magazine.

Bosch, R. GmbH. 1991. CAN Specification. Version 2.0 ed.

Breeze, E. 1998. Fieldbus for Manufacturing and The Process Industries. 3rd Ed. Wales, UWCN.

Bryan, E. A. and Bryan, L.A. 1997. *Programmable Controllers.* Work book and Study Guide. Publisher, p4.

BSI. 2000. *Guide to the Evaluation of Fieldbus Protocols-Selecting the Best Fieldbus for your Application.* 2000. London: British Standards Institute.

Caro, D. 1998. *Field Networks Worldwide Outlook,* Arc Advisory Group. Massachusetts.

Caro, R. 2000. Wireless: *Automation's next frontier.* http//www.isa.org/journals/ic/feature. 12th October, 2000.

CENELEC. *Info- About CENELEC.* http://www.cenelec.org/info/about.htm. 15th May, 2001.

Datamonitor Industrial Ltd. 1999. *Developments and Customer Opinions on Fieldbus.* Volumes 1 & 2, London: Datamonitor Industrial Ltd.

Farsi, M and Barbosa, M.B.M. 2000., *CANopen Implementation: applications to industrial networks.* Philadelphia: Research studies Press.

Fieldbus Foundation Journal.1997, http://Honeywell.com/Pub/Journal, 21st Feb 2001.

Gruhler, G. 1993. *Bus Selection Procedure.* ASPIC Project- Report D2. Germany: STA Rutlingen.

Honeywell.1999.*SDS Physical Layer Specification,* Version 2.0, Issue 3.

Honeywell.1999.SDS Application Layer Protocol Specification, Version 2.0, Issue 4.

Hoske, T, M. 1998. *Connect to the Benefits of Digital Industrial Networks,* Control Engineering Online, 2001, http/www.controleng.com/archives/1998.

Hulsebos, R. 2000. *Enter Ethernet, Exit Fieldbus?* Industrial Ethernet Journal. Issue 4, pp. 8-10.

IDC Technology (Instrument Delta Communications). 1994. *Data Acquisition using Personal Computers and Standalone Systems.* Training course notes. Surrey.

IEC 1158, *Fieldbus standard for Industrial communication.* Draft Part 1. Introductory guide p. 15.

IEC. *Inside the IEC: General Information.* http://www.iec.ch/gnotel-e.htm. 14th May, 2001.

IMS. 1999. The European Market for Fieldbus-A Users Survey. Northants: IMS.

Industrial Data Communications. Westermo. 4th edn. 2001. Sweden: Westeras Media.

Interbus. 2001. *Interbus System Technology Basics*, http//www.interbusclub.com/en/technologie/index.html. 23rd March, 2001.

IAONA.2001. *Proprietary and "standard" control networks vs Ethernet.* http//iaopennetworking.com/English/Organizations/Isssues.html. 12th June 2001.

ISA. 2001. *Rockwell to cut 500 jobs, close some plants*. Industrial computing journal Online, http://www.isa.org/journal/ic/news/1,1160,1869,00.html, 11th June 2001.

ISO. *About ISO.* http//www.iso.ch/infoe/aboutiso.htm. 15th May, 2001.

Johnson, D. 1999. *Taking the Open Road.* Control Engineering Magazine, pp. 48-56.

Jordan, L and Churchill, B.1994. *Communications and Networking for the PC.* 5th edn, Indionapolice, New Rider Publishing.

Katzel, J. 1997. *Moving Down the Path to Open Systems*. Plant Engineering Magazine.

Kepner, C.H and Tregoe, B.B. 1981. *The New Rational Manager*. New Jersey: Princetown Research Press.

Kurzweil, R. 1999, *The Age of Spiritual Machines*. Viking penguin.

Lane, D.P. 1997. *Sensor Review*. Sensor gateway to Fieldbus, pp. 211-216.

LeBlanc, C. 2000. *The Future of Industrial Networking and Connectivity.* Industrial Ethernet Journal. Issue 2, pp. 6-8.

Levine, S.W. 1984. *Programmable Controllers.* CRS Press.

Liptak, G. B. 1995, *PLC's and Other Logic Devices*. Process Control 3rd Edn. Chilton, p722-723.

LonMark, 1999. Introduction to the Lonworks system. Ver 1.0, http://www.lonmark.org/products/guides, 5th February 2000.

Lowe, N. 2000. *Fieldbus Take-up,* Industrial Technology Magazine, pp. 64-65.

Matteo, M. 1999. *Fieldbus in Industry: what is at Stake, Paper.*

Morley, R. and Moody, P. 1999. *The Technology Machine.* Free Press.

ODVA . 1999. *Connected with DeviceNet.* Product Catalogue, International Edition.

Paterson, C. G. January 1998. *Selecting the Right Industrial Network.* Control Engineering Magazine, pp. 61-66.

Piggin, R.S.H. *DeviceNet Installed Costs.* Doctor of Engineering dissertation. University of Warwick, 1999.

Piggin, R.S.H. The Implementation of Fieldbus Technology, MSc dissertation, 1997.

Pinto, J. 2000. *On the Frontiers of a New Millennium.* Instrumentation control & systems.

Pinto, J. October 2000, *Companies in Trouble.* Controls Intelligence and Plant systems journal, pp. 4-13.

Quinn, J. 1995. *Digital Data Communication.* USA: Prentice Hall International (UK) Ltd.

Regberg, M. 1998. Venture Development Corporation. *The U.S. Market for Industrial Automation Products Incorporating Device/Sensor Buses: ASI, CAN (DeviceNet, SDS), Interbus-S, LonWorks, Profibus DP and Seriplex.* 2nd Edition. Massachusetts: Venture Development Corporation.

Rockwell Automation. 1999. *DeviceNet Starter Kit.* Rockwell Automation Publication Cat No.DN-6.5.16.

Rockwell Automation.1999. *DeviceNet Cable System: Planning and Installation Manual.* Rockwell Publication Cat No. DN-6.7.2.

Rockwell Automation. 1997. *DeviceNet Scanner Module: Installation Instructions.* Rockwell Publication Cat No. 1771-SDN/B.

Rolf. 1998. *Advantages of Fieldbus,* http://rolf.ece.curtine.edu.au, 4th July 2000.

Seriplex. 1997. White paper: Distributed, Intelligent I/O for Industrial Control and Data Acquisition. htp//www.seriplex.org/part4/wp.html. February 14th, 2001.

Seriplex. 2000. Standards Specification. Version 2. http//www.seriplex.org/part4/seriplex_standard.pdf. November 6TH, 2000.

Squibb, N. 1985. *Broadband vs Baseband- The choice for Ethernet,* User Journal, pp. 43-45.

Steinhoff, A. 1998. *Open: The Opiate of the Masses,* http//www.automationmag.com/curr/article1.phtl?id=63, May 14th, 2001.

Svancia, B. 1998. *Understanding Device Level Buses.* Minneapolis: Interlink BT.

Tagney, B and O'Mahoney, D. 1988. *Local Area Networks and their applications.* Hertfordshire: Prentice Hall International (UK) Ltd.

TurnBull, G. 1999. *Is Ethernet the Answer to the Fieldbus Dilema?.* Industrial Ethernet Journal, Issue 4, pp.4-9.

Watson, K. 2000. *Process Automation with Fieldbus.* New Food Magazine, Volume 3 Issue 3, p72.

APPENDIX A

KEPNER TREGOE MANUAL

A.1 Kepner Tregoe Manual

FOUR

Decision Analysis

IN THIS CHAPTER

The Conditions and Elements of Making Choices
The Major Elements of Decision Analysis
The Techniques of Decision Analysis

THE CONDITIONS AND ELEMENTS OF MAKING CHOICES

Decisions must be made and actions must be taken in all organizations. It is up to the appropriate people in the organization to select the actions, determine how to carry them out, and take responsibility for their successful implementation. Often, however, there is uncertainty over how to proceed. People find it hard to think together about the choices they must make. They cannot agree on where or how to start making the decision. As a result, they may overlook important information, fail to consult the proper people, and make mistakes. Organizational decision making is often not as good as it should be.

Although people enjoy being involved in decision making, many shun the task because of the controversy involved. Lacking commonly accepted, unbiased procedures, decision making becomes a shoving contest among those with differing points of view. The individuals with the most power prevail. Others accept decisions in order to save face and avoid direct confrontation.

When people are provided with a common approach to decision making, they find they can indeed work as a team. There is more sharing of relevant information. Differing positions are more successfully reconciled because the process of decision making is less biased. Inevitably, the quality of decision making improves.

THE THINKING PATTERN FOR MAKING CHOICES

Decision Analysis is a systematic procedure based on the thinking pattern we use when making choices. Its techniques represent expansion and refinement of the elements in this thinking pattern:

▷ We appreciate the fact that a choice must be made.

▷ We consider the specific factors that must be satisfied if the choice is to succeed.

▷ We decide what kind of action will best satisfy these factors.

▷ We consider what risks may be attached to our final choice of action that could jeopardize its safety and success.

We may employ this thinking pattern very swiftly, even unconsciously. Although we may skip one or more of the elements in a cursory analysis, each element plays some role in determining every choice we make. When we are confronted with simple, repetitive choices, memory and experience enable us to consider in a fraction of a second the specific factors that must be satisfied. This is seen typically in the choices we make when we drive an automobile. We would be incapable of driving without the ability to make decisions and choices quickly and automatically, unconsciously using all the elements of the choice-making thinking pattern.

Nobody needs to be told that excellence in making choices is critical to individual and organizational success. Everyone knows that choices made today influence our lives tomorrow. What is not so obvious is *how* to use the information available to make the decision today that will be lauded as excellent tomorrow and bring credit to everyone associated with it. Nor so obvious is *how* we ought to use that information, how we can avoid getting bogged down in details, how we can avoid missing the details that must be recognized, and how we can escape being confused and intimidated by the uncertainties of the future.

Behind most decisions lie a myriad details. Some are highly important, some insignificant. The quality of available information may not match our needs. There may not be enough information. There may be so much that it overwhelms us. Perhaps the degree of relevance of available information is unclear. Over every decision hovers some measure of uncertainty—for all decisions will play out their day on a stage somewhere in the uncertain future. Good decision making, like good problem solving, depends heavily on experience and judgment. In both areas of managerial responsibility, however, it is within the framework of a *systematic procedure* that experience and judgment produce successful results and a reputation for managerial excellence.

Case History: Hiring a New R&D Director

Making good choices depends on three elements: the quality of our *definition* of specific factors that must be satisfied, the quality of our *evaluation* of the available alternatives, and the quality of our *assessment* of the risks associated with those alternatives. It all sounds so straightforward that we wonder how bad decisions come to be made. Here is one simple and highly typical example.

"We need to increase the research and development capabilities of this organization." That was the statement made by a member of the Executive Committee of a fast-growing social research organization.

Over a period of two months, the committee discussed this need and considered alternative actions. With what result? The committee hired a new director of R&D, an individual who had worked for a competitor and was considered "the best."

"Best for **what**?" is the question that should have been asked when the statement of need was first made.

After the new director had been in the job for six months, the Executive Committee came to three conclusions: (1) The new director was not "best" for their organization; (2) The alternative of "new director" did not really address any of the firm's pressing R&D concerns; (3) The question of a suitable direction for R&D at that point in the company's life had never been adequately discussed.

The committee had made a poor decision. Why? Because the committee had no clear purpose to begin with, it had not discussed the organization's specific needs in matters of research and development. Consequently, the committee had not understood the kinds of alternatives most likely to benefit the organization. Yet, at the time the decision was made, everyone was positive and enthusiastic about the choice.

> "What we said later," one member of the committee told us, "was that, given the information we had at the time, it seemed like the right way to go. But I don't buy it. Given the information we **could** have had and the actions we **might** have taken had we really thought through our situation, I don't believe that the decision to hire 'the best' away from a competitor would have seemed like the right way to go. Everyone was hung up on the assumption that there was somebody out there who could come in and work miracles. It was never put in just those words, but it was on that assumption that the whole decision was really based."

Many, many decisions are characterized by this kind of thinking. A good decision can only be made in the context of ***what needs to be accomplished.*** No alternative is any better than the opportunity it holds for us to do the job that has to be done.

The purpose of Decision Analysis is to identify what needs to be done, develop the specific criteria for its accomplishment, evaluate the available alternatives relative to those criteria, and identify the risks involved.

For the remainder of this chapter, we will explain the major elements in the process of Decision Analysis and show how the process is used. Our example involves a relatively simple, straightforward choice among four possible courses of action.

THE MAJOR ELEMENTS OF DECISION ANALYSIS

THE DECISION STATEMENT

In Problem Analysis, we begin with a *problem statement,* which names the situation to be resolved. In Decision Analysis, we will begin with the *decision statement,* or with naming the "choice" dilemma that is to be resolved.

Resolution in Problem Analysis consisted of a confirmable answer to the question "Why?" Resolution in Decision Analysis will consist of an answer to the questions "To what purpose?" "Which?" and "How?"

A decision statement provides the focus for everything that follows and sets the limits of the choice. The criteria to be developed will follow from it, describing in detail the requirements of the decision. The alternatives will be judged on their ability to meet these requirements. Because the decision statement sets all these activities in motion, it has another quality in common with the problem statement: ***The way it is worded deserves careful attention.***

A decision statement always indicates a choice, some kind of action and its intended result: "Select a new director of quality" or "Choose a site for our new West Coast office." It also indicates the ***level, or implied prior decisions,*** at which the decision is to be made. "Select a new director of quality" indicates we have already decided that a new director is needed.

In the case we presented earlier—"We need to increase the research and development capabilities of this organization"—the decision failed chiefly because no thought was given to the level of the decision. In fact, it was not clear that there was even a choice to be made. The statement of purpose gave the decision-making team no guidance and set no limits, up or down, on the range of alternatives that would be considered. The only stage it set was one on which an alternative-driven solution could assume the starring role.

The Objectives for the Decision

Objectives, in our terminology, are the criteria for the decision—the specific results and benefits the decision is to achieve. We establish these objectives once we agree upon the correct statement of our decision. We do this before discussing alternatives, sometimes even before identifying alternatives. Decision Analysis is the antithesis of identifying a course of action and then building a case to support it. Instead, we are moving from what needs to be accomplished toward the alternative that can best accomplish it. For example, if we want to hire a new executive, we are more likely to make a good choice if we ***first*** identify the qualities of an ideal candidate and ***then*** begin the interviewing process. No experienced manager needs to have this reasoning spelled out. Objectives are clear measures of the ends we want to achieve, for only with clear measures can we make reasoned choices.

MUSTs AND WANTs

We divide the objectives into two categories: MUSTs and WANTs. The MUST objectives are *mandatory*; they *must* be achieved to guarantee a successful decision. They may not be our most important objectives. Rather, they are minimum requirements that any alternative must provide to be meaningful. When the time comes to assess alternatives against our objectives, any alternative that cannot fulfill a MUST objective will immediately drop out of the analysis.

These objectives must be *measurable* because they function as a screen to eliminate unacceptable alternatives. We must be able to say, "This alternative *absolutely* cannot fulfill this objective; it cannot meet a requirement that is mandatory for success." For example, a MUST objective in a hiring decision might be "Two years' experience as a supervisor in this industry." If that length of experience is mandatory, then there is no point in considering any candidate who hasn't put in the two years.

Of course, it is important to understand why an objective is mandatory. We might ask what benefit will we gain from a candidate with two years' experience. If there are other acceptable ways to gain that benefit, then two years' experience is not truly mandatory.

"Two years' experience" also needs to be a *reasonable* objective. Can we reasonably expect to find alternatives that satisfy this MUST objective? Given the remuneration for the position and our location, can we expect to find candidates with two years' experience? If we cannot and two years' experience is truly mandatory, then we may need to re-think the decision statement or some of the other objectives.

All other objectives are categorized as WANTs. The alternatives we generate will be judged on their *relative* performance against WANT objectives, not on whether or not they fulfill them. The function of these objectives is to give us a comparative picture of alternatives—*a sense of how the alternatives perform relative to each other.*

An objective will be stated frequently as a MUST and then be rephrased as a WANT so that it can perform both functions. For example, "Two years' experience in this industry" (MUST) may be rephrased as "Maximum experience in this industry" (WANT). Now, when we come to evaluate the alternatives, we can make two kinds of judgments. First, candidates with less than two years' experience will be eliminated. Second, the remaining candidates will be judged relative to each other based on how many years of experience each has had.

Here is an example of a high-priority objective that could not be used as a MUST: "Interacts well with managers at all levels." No matter how important this objective may be, it concerns an ability that can be measured only in a subjective way. All four job candidates may meet this objective, but *some will meet it better than others*. This is exactly what we want to know: Who meets it best? Who is equally good? How well do others compare to the best performer?

Unlike a MUST objective, we are less concerned with finding alternatives that satisfy the objective minimally and more concerned with how the alternatives perform relative to each other. A WANT objective is not necessarily less important than a MUST; it simply serves a different purpose.

Someone once succinctly described the functions of these two kinds of objectives by saying, "The MUSTs decide who gets to play, but the WANTs decide who wins."

Alternatives

An ideal alternative perfectly fulfills every condition set for it without adding new difficulties. Unfortunately, ideal alternatives are rare. We must, therefore, evaluate each available alternative by measuring it against all of our objectives. It is the relative quality of that fit that concerns us.

If we must choose among several alternatives, we will have to decide which one will best fulfill our objectives with the smallest acceptable risk. In other words, we try to make a *balanced choice*. An alternative that best accomplishes the objectives but carries severe risks may not, after all, be the best choice. Another alternative, perhaps less exciting but safer, may be the best balanced choice.

If there is only one alternative, we must decide whether it is good enough to accept. In this case, our evaluation will focus on its relative worth compared with a perfect, but unobtainable, alternative.

If we must choose between a current and a proposed course of action, then we consider both to be alternatives. We evaluate their performance against our objectives just as we would if both had been proposed. Whatever is currently being done is, after all, an alternative; the choice is whether to continue that way or find another, better way.

If, in the absence of *any* alternative, we must create something new, we can usually build an alternative from available components. We then choose the best and most feasible combinations, treat each as a separate alternative, and evaluate all of them against an ideal model of an alternative.

In the next chapter, we will examine true examples of these situations and explore the sources of alternatives.

The Consequences of the Choice

The final step in Decision Analysis is the search for possible adverse consequences of all feasible alternatives.

The negative consequences of any action are as tangible as its benefits, sometimes more so. Once a decision has been made and implemented, any of its negative effects will eventually become real problems. The effects of decisions—good or bad—always outlive the decision-making process that produced them. And which effects—good or bad—are longest remembered? "The evil that men do," wrote Shakespeare, "lives after them, the good is oft interred with their bones...." Some things haven't changed at all in almost four hundred years.

We must thoroughly explore and evaluate the possible adverse consequences of any alternative *before* we make a final decision. This is the only opportunity we will ever have to deal with such effects at no cost beyond a little intellectual effort. We must recognize possible adverse consequences before they occur and take them into consideration as part of our decision. Having recognized and assessed them, we may be able to avoid them altogether or take steps in the present that will reduce their effect in the future. A risk attached to an alternative is not necessarily a totally damning factor—*provided that someone*

sees it while there is time to do something about it. Any evaluation and choice that omits a disciplined, systematic search for potential negative consequences is an invitation to disaster.

Decision Analysis seldom deals with certainties. The further into the future a proposed action extends, the less certain it can be. It is because of these uncertainties that the process of Decision Analysis depends on our judgments, evaluations, experience, and intuitive feelings. All of these supply the valid data we need to support the correct decision we must make.

To set aside feelings, instincts, and the inner voice that says, "I don't feel right about this," is to throw away a valuable resource. It leads to such errors as hiring a person you don't like and can't work with just because "the résumé looked so good, and I was trying to be objective." That is not good decision making. A good decision is one that will work. Overlooking factors that make a choice unworkable is a fundamental mistake. A reasonable selection and a good decision always depend on thorough study and careful evaluation of *all* relevant information.

Decision Analysis is a methodical, systematic process. But it is also as creative and innovative a process as its users choose to make it.

THE TECHNIQUES OF DECISION ANALYSIS

The techniques of Decision Analysis are divided into these activities:

▷ State the decision.

▷ Develop objectives.

▷ Classify objectives into MUSTs and WANTs.

▷ Weigh the WANTs.

▷ Generate alternatives.

▷ Screen alternatives through the MUSTs.

▷ Compare alternatives against the WANTs.

- Identify adverse consequences.
- Make the best balanced choice.

STATE THE DECISION

Case History: Purchasing the Best Personnel Information System

The following situation illustrates the use of Decision Analysis techniques. It concerns the selection of software from among four potential suppliers.

Our client's decision statement was: "Select the Best Personnel Information System for [Our] Corporation." The people involved in making this decision were the vice president of operations, the vice president of human resources, the director of management information systems, and one of the firm's attorneys. They worked as a team to decide three things: the level of the decision, who was to delegate necessary research tasks to others in the firm, and who was to use the resulting information to reach the final conclusion. The team was not involved in the research required to make the evaluation.

Operating this way, the team arrived at its conclusion after three one-hour sessions held over a period of two weeks. Compared with previous, similar decision situations, this was considered a tremendous saving of time and effort.

The decision statement indicated not only the purpose of the decision but also the level at which it would be made. It set the stage for the *kinds* of alternatives that would be considered. Had the statement been worded: "Select a method to improve our method of personnel information recording and reporting," the character of the decision would have been different. The selection of a new system would have appeared as one of several alternatives.

A decision statement is, in a way, the product of previous decisions. The team had already decided that it needed a new system to replace all the present methods and procedures. Thus, the wording of the decision statement immediately vetoed a dozen other possible decisions that might have been made.

DEVELOP OBJECTIVES AND CLASSIFY INTO MUSTS AND WANTS

What must the new system do? What would the team *like* it to do in addition? What constraints affect the choice of a new system? Such are the questions that every team of decision makers has to ask in order to begin setting objectives. The answers to these questions will result in a list of objectives. The objectives will then be classified as MUSTs or WANTs.

Among our client's MUST objectives for the new personnel information reporting system were these:

MUST be capable of:

- Meeting Equal Employment reporting standards.
- Providing reporting to management, using Report Writer.
- Capturing compensation information.

Each of these objectives was considered mandatory, and each was measurable: a system could offer these features or it could not. These objectives were also considered reasonable. Several alternatives were known to meet these minimum requirements.

The list of WANT objectives represented additional desirable, but not mandatory, criteria. Following are five of the seventeen WANT objectives that appeared in the analysis:

- Captures individual job histories and special capabilities.
- Can be implemented within six months.
- Meets Health and Safety reporting requirements.
- Reduces current paperwork.
- Protects employee confidentiality.

WEIGH THE WANTS

Once the WANT objectives had been identified, each one was weighed according to its relative importance. The *most* important objective was identified and given a weight of 10. All other objectives were then weighted in comparison with the first, from 10 (equally important) down to a possible 1 (only one-tenth as important).

No attempt was made to rank the objectives. The purpose of the 10 to 1 weighting scale was simply to make visible the relationships among these objectives. What mattered most? What could be done without, if necessary?

When the time comes to evaluate the alternatives, we do so by assessing them *relative to each other* against all the WANT objectives—one at a time. This is why it is critical at the outset to identify the most important objectives. It is pointless to know that a particular alternative satisfies nine out of ten WANT objectives if, in fact, it is the tenth that is most crucial to the success of the decision. We must also examine the *balance* of WANT objectives and look for certain danger signals:

▷ Too many high numbers may indicate either unrealistic expectations or a faulty perception of which objectives can guarantee success.

▷ Too many low numbers suggest that unimportant details may be smothering the analysis.

▷ Too many objectives reflecting the vested interest of a single stakeholder may lead to an unworkable decision. This is especially true if other stakeholders are equally affected by the final decision.

▷ Loaded objectives—those that guarantee a smooth passage for a certain alternative and penalize all others—can make a mockery of an analysis.

These are the weights our client team assigned to the five WANT objectives:

- Captures individual job histories and special capabilities 9
- Can be implemented within six months 10
- Meets Health and Safety reporting requirements 8
- Reduces current paperwork 5
- Protects employee confidentiality 3

GENERATE ALTERNATIVES AND SCREEN THROUGH THE MUSTS

In this case, alternatives were fairly clear-cut. The team identified four leading suppliers of the system they wanted and then launched the evaluation.

In this evaluation, an alternative either meets all the MUST objectives (GO) or does not (NO GO). A NO GO is immediately dropped from further consideration.

The MUSTs, you may remember, were:

- Meeting Equal Employment reporting standards.
- Providing reporting to management, using Report Writer.
- Capturing compensation information.

To the surprise of most people on the team, one highly regarded system failed at this point. It could not provide the Report Writer feature. The alternatives are shown in Figure 7.

Note that the information columns in Figure 7 tell us *why* an alternative has passed or failed. By listing this information, the process has become visible. Facts, opinions, and judgments are on record. A written summary exists for future reference, leaving nothing to be memorized or forgotten. And necessary information is available for anyone who must approve the final decision.

Having eliminated Company D, the team now carried the three remaining alternatives into the next phase: comparative evaluation on the basis of the WANT objectives.

COMPARE ALTERNATIVES AGAINST THE WANTS

Beginning with the first WANT objective—"Can be implemented within six months" (weight of 10)—the team evaluated the information it had gathered about Companies A, B, and C.

Company A had given an estimate of six months with a guarantee; Company B, six months but would not commit to a set date; Company C, four months and seemed reliable. The vice president of operations was less certain about Company B. He had heard that two of B's customers had reported slightly delayed implementation; otherwise, they were satisfied with the service they had received.

Based on this information, the team decided that Company C, with a reliable estimate of four months, *best* met the implementation objective. They gave Company C a score of 10 on that objective, and gave relative scores of 9 to Company A and 5 to Company B. What purpose do these numbers serve? *They help to reflect our judgments.*

At this point in the analysis, all objectives have been sorted out and made visible, and the WANTS have been weighed. Now the alternatives will be sorted out, permitting us to judge the relative advantages of each one. For example, how good an implementation job can Company C do *compared with Companies A and B?* As each company is scored against each of the WANT objectives, its relative overall performance and ability to produce desirable results will gradually become clear.

Figure 8 shows the judgments the team made of the relative performances of the three alternatives, scored against all of the WANT objectives.

People sometimes are bothered when none of the alternatives seems to deserve a 10. They are even more disturbed when none of

FIGURE 7 **ALTERNATIVES SCREENED THROUGH MUST OBJECTIVES**

MUST OBJECTIVES	***COMPANY A***	***GO/NO GO***	***COMPANY B***	***GO/NO GO***
Meets Equal Employment reporting standards	Meets government requirements. More detail available	GO	Meets government requirements. More detail available	GO
Provides management reporting using Report Writer	All reports use Report Writer	GO	Standard reports can be exported to Report Writer	GO
Captures compensation information	In standard package and can be added to	GO	In standard package	GO

the alternatives performs well on a particular objective. We give a 10 to the alternative that comes *closest* to meeting the objective, and score the other alternatives *relative to it.* We are not seeking an ideal through this comparative evaluation. What we are seeking, instead, is an answer to the question: "Of these (real and attainable) alternatives, which best fulfills the objective?"

There is one caution: If, during the scoring step, a statement such as "none of the alternatives is much good" comes up repeatedly from one objective to the next, then something is obviously wrong. Either more alternatives are needed or the objectives are unrealistic, and no *real and attainable* alternative can fulfill them. But this is a rare circumstance. People in a decision-making position are usually there because they have a good grasp of what is feasible; they do not devise unattainable objectives.

At the other extreme, all alternatives may perform well on nearly all objectives. This is caused by a set of objectives so loose that any of a number of similar alternatives will be equally good at satisfying the requirements of the decision. The simple remedy is to go back to the list of WANT objectives and make them tighter, more demanding, and more numerous. The alternative that really does offer more will then stand out.

COMPANY C	*GO/NO GO*	*COMPANY D*	*GO/NO GO*
Meets government requirements. More detail available	GO	Meets government requirements using standard reports. Cannot be modified	GO
Standard reports can be exported to Report Writer	GO	Cannot use Report Writer	NO GO
In standard package and can be added to	GO	—	

Now we need answers to two questions: How does each alternative perform across the board? How does it compare to the other alternatives on total performance against WANT objectives? We can answer the questions by computing the weighted scores of each alternative.

A ***weighted score*** is the score of an alternative multiplied by the weight of the objective to which the score refers. For example:

> Company A scored 9 on the WANT objective "Can be implemented within six months." That objective has a weight of 10. Therefore the **weighted score** of Company A on that objective is 90 (9 x 10).

We continue by computing Company A's weighted scores for ***all*** the WANT objectives. Then we add up all of the weighted scores to produce the ***total weighted score*** for the Company A alternative. We complete this step by repeating the procedure for the other alternatives, producing the results that appear in Figure 9.

The total weighted scores function as ***visible comparative measurements*** of the alternatives. Their numbers indicate that one alternative is more viable than the others, that one course of action is apparently more valuable than the others. There is nothing magical about

FIGURE 8 **ALTERNATIVES COMPARED AGAINST WANT OBJECTIVES**

WANT OBJECTIVES	*WEIGHT*	*COMPANY A*	*SCORE*
Captures individual job histories and special capabilities	9	Can be written into program	6
Can be implemented within 6 months	10	6 months with guarantee from vendor	9
Meets Health and Safety reporting requirements	8	Exceeds requirements; very flexible	10
Reduces current paperwork	5	Minimum forms required; can use current documentation	10
Protects employee confidentiality	3	Can customize security	10

the numbers. A base of 10 to 1, for both the weighting of WANT objectives and the scoring of alternatives, is a simple, logical, and productive means for producing good results.

As Figure 9 indicates, the total weighted scores were 304 for Company A, 218 for Company B, and 302 for Company C. As we have said, this is a sampling of the full-blown analysis that included seventeen WANT objectives. For the record, the complete scores were: 1009 for Company A, 752 for Company B, and 878 for Company C. Company A, then, satisfied the objectives of the decision to a greater degree than either of its competitors.

Under certain conditions we can vary the way we assign numerical weights. If a manager must work with fifty or a hundred objectives, for example, these can be broken down into categories, with a weight (or percentage of influence) given to each category. In this instance, a single WANT objective may bear a weight of 10, but belong to a category with a comparatively low weight. While the logic of the Decision Analysis process remains unchanged, this modification of technique reflects the particular requirements of the decision.

COMPANY B	SCORE	COMPANY C	SCORE
In standard package	8	In standard package and can be added to	10
Vendor says maybe 6 months	5	4 months	10
In standard package	7	In standard package	7
Uses minimum forms; cannot customize	5	Uses minimum forms and can make custom forms	7
No security on data file but can be added	5	Password security on Report Writer	7

The Tentative Choice

The total weighted score gives us a tool for selecting a *tentative choice.* Although the tentative choice often graduates to the status of *best balanced choice,* it should never do so before we explore the potential risks involved. Four decades of experience have shown us clearly that elimination of this final step of Decision Analysis—because "one alternative is so obviously the leader"—can negate the value of all work done up to this point.

IDENTIFY ADVERSE CONSEQUENCES

If exploring potential risks is so important, why do people often fail to do this step? There are several understandable reasons. If an analysis of three alternatives produces total weighted scores of 700, 350, and 210, it may seem a waste of time to brainstorm for potential risks. In another case, someone may be reluctant to inject a dose of pessimism when the rest of the team enthusiastically exclaims, "We've done all this work! And we've produced this great alternative!" That

FIGURE 9 **ALTERNATIVES AND THEIR TOTAL WEIGHTED SCORES**

WANT OBJECTIVES	*WEIGHT*	*COMPANY A*	*SCORE*	*WEIGHTED SCORE*
Captures individual job histories and special capabilities	9	Can be written into program	6	54
Can be implemented within 6 months	10	6 months with guarantee from vendor	9	90
Meets Health and Safety reporting requirements	8	Exceeds requirements; very flexible	10	80
Reduces current paperwork	5	Minimum forms required; can use current documentation	10	50
Protects employee confidentiality	3	Can customize security	10	30
Total Weighted Scores				**304**

one doubtful member of an optimistic decision-making team may very well hide those negative opinions. One last and very common reason for dropping the step of risk exploration is this: We are often unable or unwilling to apply the lessons of the past to the decisions of today.

One manager told us that, early in his career, he had meekly suggested to his boss that the potential problems of an alternative under consideration had not been adequately considered. Even more meekly he reminded his boss that a decision made in another department had seriously backfired several months before. "That," his boss replied scornfully, "was *them* and *then*. And this is *us* and *now*." The subject was dropped. The decision proved to be a good one, but that did not prove the young manager wrong. A year or two after a decision is implemented, nobody regrets the time spent probing its risks. It is a mere fraction of the time spent in regret over a risk that should have been explored but was not.

In the earlier steps of Decision Analysis, we try to make our objectives as comprehensive and our evaluation of alternatives as rigorous as possible. But these activities go just so far. They must be followed

COMPANY B	SCORE	WEIGHTED SCORE	COMPANY C	SCORE	WEIGHTED SCORE
In standard package	8	72	In standard package and can be added to	10	90
Vendor says maybe 6 months	5	50	4 months	10	100
In standard package	7	56	In standard package	7	56
Uses minimum forms; cannot customize	5	25	Uses minimum forms and cans make custom forms	7	35
No security on data file but can be added	5	15	Password security in Report Writer	7	21
		218			**302**

by the most creative and difficult step in the process: *considering the consequences of alternatives.* This entails answering at least the following questions.

If we choose *this* alternative:

▷ What are the implications of being too close to a MUST limit?

▷ Where might information about this alternative be invalid? What are the implications?

▷ What could go wrong, in the short- and long-term, if this alternative were chosen?

▷ What could keep this decision from being successfully implemented?

In this step of the process, we try to destroy our best alternatives one at a time. We become destructive, negative, and pessimistic. The degree to which managers accept this process is determined largely by how experienced they are. Experience teaches us that there are no awards for past optimism over current failures. This fact is borne out by the difficulty of finding out who, in any organization, was really responsible for the very worst decisions that were ever made.

We begin this step with the *tentative* choice—the alternative with the highest total weighted score. We examine it by itself. We examine its probabilities of failure or potential trouble. Remember that this is *never* an exercise in comparisons. We do *not* say, "Alternative A is more likely to produce this problem than Alternative B." Comparison is not a useful approach. Each alternative must be examined separately.

We then rate the adverse consequences of an alternative on the basis of *probability and seriousness*: What is the probability that this (adverse consequence) will occur? If it (the adverse consequence) does occur, how serious will it be? We can use ratings of High, Medium, and Low (H,M,L) or a scale of 10 (highly probable/very serious) to 1 (unlikely/not at all serious). The 10 to 1 system is fine—provided that we avoid the temptation to start multiplying: "Probability of 9 x Seriousness of 3 = 27." (We did this in our first book, *The Rational Manager*, and went on to add these numbers for each alternative. This produced "adverse consequence totals" for all the alternatives. We have found over the years that this is not useful information.) If we permit the numbers to obscure the information that produced them, we can lose sight of the serious adverse consequences.

We will not lose any sleep over an adverse consequence of low probability and minimal seriousness. But we will be very attentive if an adverse consequence is considered both highly probable and very serious.

Following are some of the adverse consequences for the alternatives that scored the highest. These were identified during the final step of the Personnel Information System decision.

Company A:	If the company is to be sold soon, then support could be affected.
Probability?	Medium
Seriousness if it occurs?	High

Company C:	If this is a new company with inexperienced employees, then they may not meet future needs.
Probability?	Low
Seriousness if it occurs?	Medium

Three factors determine the number and importance of potential adverse consequences we identify for the alternatives: the extent of their existence, our ability to find them, and our willingness to address those we find.

MAKE THE BEST BALANCED CHOICE

Having clearly identified the value each alternative can deliver and the risks each alternative poses, we are prepared to weigh the potential gains against the potential pitfalls. We ask ourselves whether or not we are willing to accept the risks of a choice to gain the benefits. If the answer is yes, then we should commit to the choice. If not, we should consider less risky, more beneficial choices.

How useful is the Decision Analysis process if potential adverse consequences can knock out the very alternative that scored the highest on the objectives we worked so hard to develop? It is *because* of the previous steps in the process, the visibility of information, and the tracking of our thinking from the decision statement to this point that we can best assess the potential adverse consequences. It is only now, with all the data before us, that we can stretch our imaginations beyond the body of facts we have amassed, survey it all, and ask: "What did we miss? Can we afford the risks involved with this choice?"

The outcome of this particular case was that our client chose to go with Company C, the runner-up in the numerical scoring. Someone had picked up a rumor that Company A might sell out within the next three years. The rumor was never substantiated but was there just the same. Moreover, Company C's youth and relatively small size seemed to offer at least as many potential advantages as disadvantages. Its management team was aggressive, ambitious, and preoccupied with service as a means of getting and retaining new business. Our client's service needs were unlikely to outstrip Company C's ability to meet them. The team made the best decision possible based on the available information and on the experience and judgment of the team members.

So how did it all turn out?

Company A did not sell out within three years. But by that time its reputation for service had been eclipsed—by Company C, the team's choice. Company C did an excellent job. It had the system in full operation within four months as promised, and it continued to treat our client as a key customer. The decision-making team remained satisfied that it had made the right choice and never regretted having considered the rumor about Company A in its deliberations.

In three one-hour sessions conducted over a period of two weeks, the team had reached a prudent decision that produced exactly the results they had hoped for: a balanced, reasoned choice of action that all could subscribe to and support—a *choice that worked* for the organization.

CHAPTER SUMMARY

Through the process of Decision Analysis, we expand from a concise statement of purpose to a number of criteria for completely defining the achievement of that purpose. These criteria give us something specific against which to evaluate available alternatives. Then, by narrowing those judgments through a systematic method of evaluation and risk assessment, we reach a final conclusion.

The power of the process lies in the ability it gives managers to make *productive* use of all available information and judgments. The process does not guarantee that perfect decisions will be made every time. Given human fallibility and the usual inadequacy of available information, there can always be errors. At the very least, however, the Decision Analysis process enables the manager to reduce the incidence of errors by providing a systematic framework for evaluating alternatives. Going beyond this simplest level of efficiency, the examples in the next chapter illustrate how much more effective Decision Analysis can be when creative and innovative managers apply the basic logic of the process to their most important choices.

APPENDIX B

SELECTION DATA AND COST ANALYSIS

B.1 Characteristics of Existing Proprietary Network

B.2 DeviceNet Cost Comparison Instruction Manual

B.3 Line 10 Saw I/O Listings

B.4 Saw Cost Analysis Excluding Premium

B.5 Saw Cost Analysis Inclusive of Premium

B.6 Line 10 External Unwind I/O Listings

B.7 Unwind Cost Analysis Excluding Premium

B.8 Unwind Cost Analysis Inclusive of Premium

B.1 CHARACTERISTICS OF EXISTING PROPRIETARY NETWORK

Allen Bradley's Remote I/O

Network Characteristics

The following are key characteristics of the Remote I/O network using the company's standard 1785 plc5/ 80E.

- Max No of Nodes (chassis) ; 64
- Max No of I/O ; 3072
- Media support; Twin axial.
- Bit Rates/sec & Cable lenghths; Typically set at 115.2K
    - 10ms @ 57.6K , 10,00ft (3048mtrs)
    - 7ms @ 115.2K , 5,000ft (1524mtrs)
    - 3ms @ 230.0K , 2,500ft (762mtrs)
- Max bit rate speed required is a BCD encoder for paper tension control approximatly 4ms
- The remote I/O network is for basic bit level devices and to provide a distributed/ de-centralised I/O system.

B.2 DEVICENET COST COMPARISON INSTRUCTION MANUAL

Rockwell Automation
Allen-Bradley

DeviceNet Toolkit (UK Version)

Installation Cost Comparison Worksheet

User Manual

Allen-Bradley has developed the DeviceNet Toolkit to provide information on installation cost to help you and other potential users to assess the use of DeviceNet. The toolkit user enters device data such as distance from the control panel, and the toolkit calculates three different installed costs: one using centralized I/O, one using distributed Flex I/O and the third using distributed devices on DeviceNet.

Of course, installed cost is only one of many factors you should consider when evaluating DeviceNet for an application. Performance, diagnostics, flexibility and other system life-cycle considerations in many cases are more important than initial installed cost.

This manual describes the operation of the toolkit, the assumptions that go into the calculations, and the defaults you may modify to tailor the toolkit to your specific situation.

Toolkit Operation

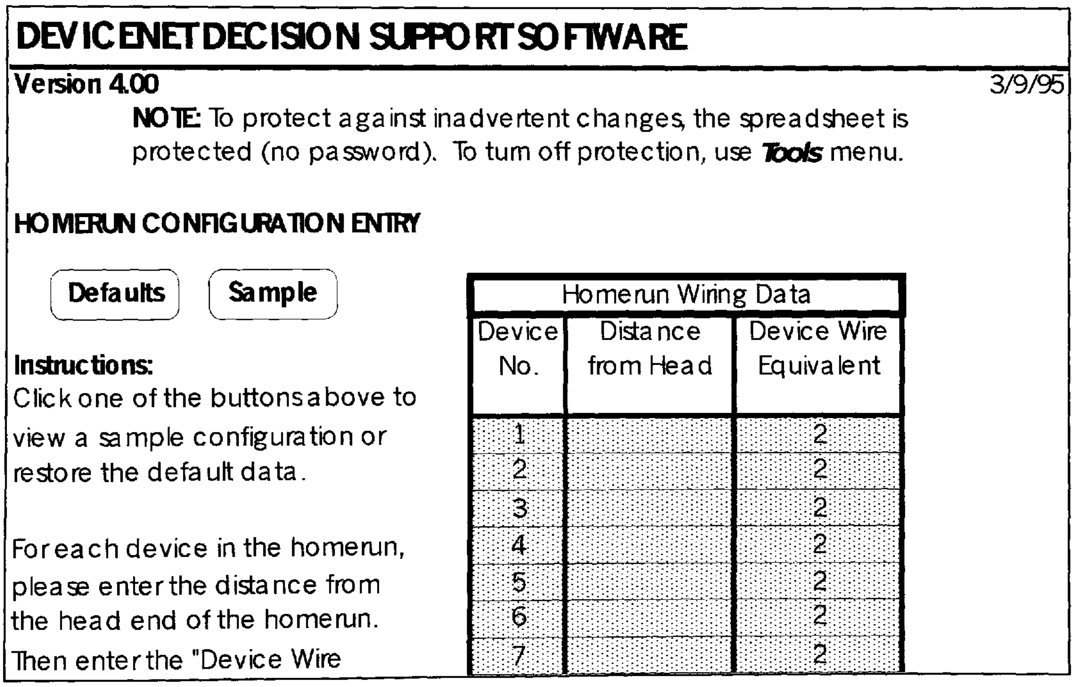
The DeviceNet Toolkit is a Microsoft Excel worksheet. You must be running Microsoft Excel for Windows, Version 5.0 to use the toolkit. Earlier versions of Excel are not compatible.

The worksheet file is NOT write-protected. You should make a working backup of the file, either on you hard disk or another diskette.

The worksheet is protected, however, to protect against inadvertent changes to the formulas and essential data. You may turn off protection by using the Excel Tools menu.

After launching Microsoft Excel, select "File Open" from the menu and select your working file "UK_SAMP.XLS". The worksheet will appear as shown in Figure 1 below.

Figure 1 DeviceNet Toolkit Initial Screen



If you have any questions about the device wiring configurations for each model, or the terms used in this manual, please refer to the section entitled "Device Model Assumptions" below.

To look at a sample configuration, click on the "Sample" button located under the heading "Homerun Configuration Entry" To return to a blank form, click on the "Defaults" button.

You may now obtain comparative cost estimates for the three models. Enter how far each device is from the main control panel and its "device wire equivalent." The maximum distance is 1600 feet.

The device wire equivalent is a gauge of the device's complexity. A single-pole switch is considered a 2-wire device, requiring 1 input point. A start-stop push button station with a pilot light would be a four-wire device with three signal wires (start and stop commands and run indication) and a common wire.

Once you have entered the device data, scroll down in the worksheet to the "Total Installed Cost" display located just beneath the Homerun Configuration Entry table. The display is shown in Figure 2.

Figure 2 Total Installed Cost Display

	1771/1746 DIRECT	FLEX I/O	DEVICENET
2. Total Installed Cost (rounded to nearest $100.00)	$0	$0	$0

Saving Your Data

When you are satisfied with the results, use "File Save As" from the Excel menu to save your work under a new filename.

NOTE: The DeviceNet toolkit file is *not* write-protected.

Device Model Assumptions

The DeviceNet Toolkit is a useful tool that provides a relative cost comparison of three installation models. By necessity, the models calculated by the toolkit are simplified representations of typical installations.

The toolkit assumes that each group of devices is wired in a single homerun, that is one conduit or cable that extends from the main control panel to the first device, then to the second device, and so on until all the devices are wired. No branching of the homerun is allowed. Figures 3, 4 and 5 below pictorially describes the three models.

You can calculate costs for a system with more than one homerun by manually adding up the results of the individual homerun cost model calculations.

Figure 3 1771/1746 Direct Model

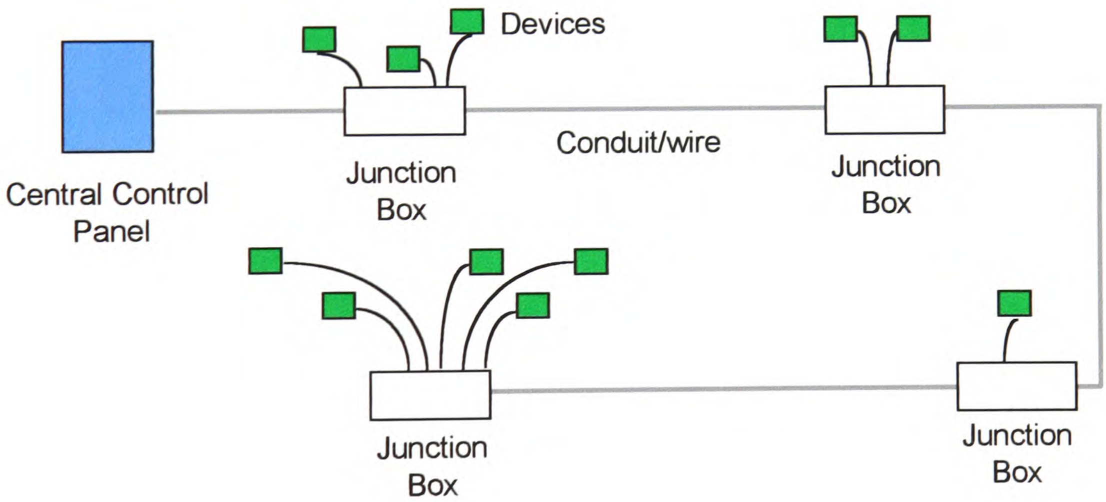


Figure 4 Flex I/O Model

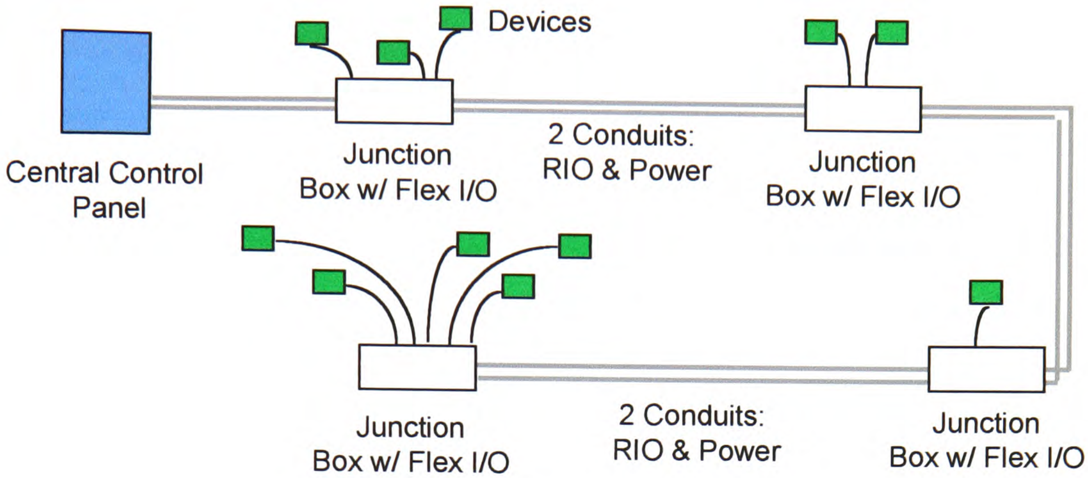
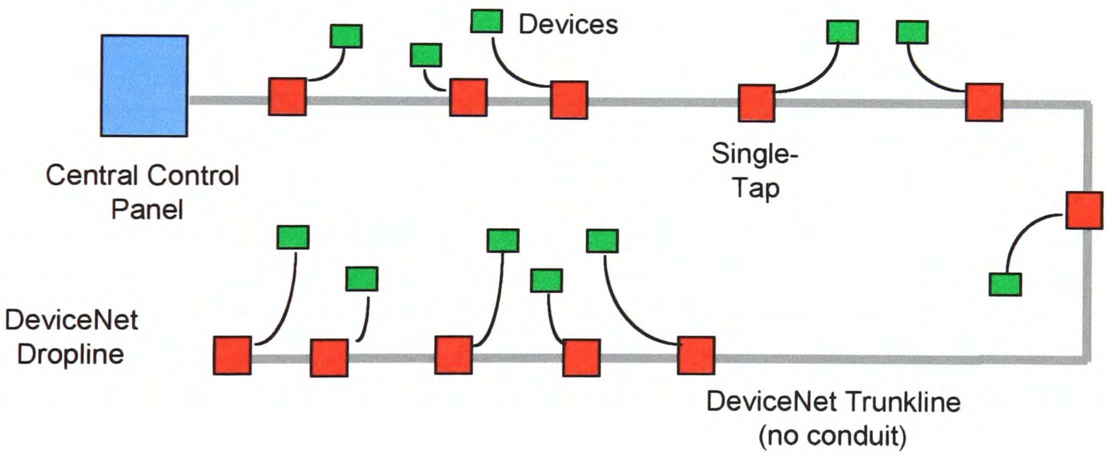


Figure 5 DeviceNet Model



Although Figure 5 shows only single taps, you may use 8-tap DeviceNet connections as described under "Tailoring" below.

The assumptions for each model are listed in Table 1 below.

Table 1 Model Assumptions

Assumptions	1771/1746 Direct	Flex I/O	DeviceNet
Homerun Wiring Method	Wire pulled in conduit	2 conduits, 1 power and 1 blue hose	DeviceNet trunk cable - no conduit
Device Wiring Method	Junction boxes with terminal blocks; flex cable to device	Junction boxes with Flex I/O blocks, flex cable to device	Single or 8-tap DeviceNet taps (as you choose), flex dropline to device
Spacing of junction boxes or taps	Function of device spacing and max. device cable length (default = 15 ft.)	Function of device spacing and max. device cable length (default = 50 ft.)	Same as device spacing
I/O Equipment cost	Based on "device equivalent wires" and "I/O points per module" (default 16)	Based on "device equivalent wires" and "I/O points per module" (default 16)	1 DeviceNet scanner card included

The following items are included in the cost models:

- 1771/1746 and Flex I/O equipment on a "cost per I/O point" basis
- Conduit, wire, junction boxes, terminal blocks
- DeviceNet trunk cable, taps, scanner module
- Labor to install conduit or trunk cable, pull and terminate wiring

The following items are NOT included in the cost models because they are assumed to be roughly equivalent between models:

- PLC processor
- Device drop cables
- Main control panel enclosure and terminal blocks

Equipment costs are approximate **nett** prices. Material and labor costs were obtained from an A-B system integrator and are based on mid-1993 costs.

The results calculated by the toolkit are intended to be used as a comparison between the three models represented in the toolkit, and should not be used to estimate the actual costs of a particular installation. Allen-Bradley makes no representation or claim as to the accuracy of the toolkit calculations.

Tailoring

You may adjust many of the defaults and assumptions used in the cost model calculations. Figure 4 shows the worksheet table with the user-editable parameters. On the worksheet, the user-editable fields are colored light green (light gray in this manual). Fields that are not adjustable by the user are colored light red (dark gray here).

Each assumption that you may tailor is explained below.

Spare Capacity

Required Spare Capacity (Wires, I/O, T.B.) - This parameter defines how many spare I/O points, wires, etc. will be provided. Default is 20%. Note that varying this parameter significantly does not impact the installed cost of DeviceNet.

Figure 4 User-editable preferences

	DIRECT	I/O	DEVICENET
SPARE CAPACITY			
Required Spare Capacity (Wires, I/O, T.B.)	20%	20%	20%
MEASUREMENTS & QUANTITIES			
Total Conduit or Trunkline Length (feet)	0	0	0
Maximum Device Cable Length (feet)	15	50	10
Qty. of Junction Boxes or Tap Locations	0	0	0
Total Number of Devices	0	0	0
Number of 8-point DeviceNet Taps			0
Input Points (per I/O card)	16	16	128
Are all wires terminated in each junction box?	n		
LABOR UNIT COSTS			
Labor Time (minutes) per Connection:	1.2	1.2	1
Labor Rate (dollars per hour):	£30	£30	£30
Cost per ft. to install Conduit or Trunkline:	£1.20	£1.20	£0.90
Cost to Install Junction Box or Tap	£13	£13	£7
Estimated Rework Labor Percentage	30%	20%	5%
MATERIAL UNIT COSTS			
Cost per Junction Box	£16	£32	
Incremental Cost of DeviceNet Device	£0	£0	£20
Cost per Terminal Block	£1		
Cost per ft. of Wire (14 AWG)	£0.10		
Cost of 3/4 Inch Conduit, per foot	£1.00		
Cost of 1 Inch Conduit, per foot	£1.00		
Cost of 1-1/4 Inch Conduit, per foot	£1.00		
Cost of 1-1/2 Inch Conduit, per foot	£1.10		
Cost of 2 Inch Conduit, per foot	£1.24		
Approximate I/O Cost (per point)	£18	£16	
Cost per DeviceNet Scanner			£400
Cost of RIO or DeviceNet Cable per foot		£0.46	£0.51
Cost per DeviceNet Connector, 1 tap			£29.00
Cost per DeviceNet Connector, 8 tap			£108.00

Measurements & Quantities

Maximum Device Cable Length (feet) helps determine how widely spaced the junction boxes will be in the 1771/1746 Direct and Flex I/O models. If you want fewer junction boxes, increase these parameters. Defaults: 1771/1746 Direct, 15 ft.; Flex I/O, 50 ft.

Number of 8-point DeviceNet Taps: If you plan on using DeviceBox or DevicePort 8-device tap connections, enter the number here. The worksheet reduces the quantity of single taps accordingly. This value resets to zero if you click the "Defaults" button.

Input Points (per I/O card) affects the calculated cost of I/O equipment. Default = 16.

Are all wires terminated in each junction box? This parameter provides for factory-built homerun sections with all wires terminated on terminal blocks for ease of field connection. If this parameter is "y" then terminal blocks are provided for all wires in each junction box. If it is "n" then terminal blocks are provided only for devices terminating at the junction box, plus 2 commons. Default is "n".

Labor Unit Costs

These parameters may be discussed with your customer and adjusted as needed:

- *Labor Time (minutes) Per Connection*
- *Labor Rate (dollars per hour):*
- *Cost per ft. to Install Conduit or Trunkline*
- *Cost to Install Junction Box or Tap*

Estimated Rework Labor Percentage: Another point of discussion with your customer, this parameter adjusts the total labor cost by factoring in time required to correct wiring errors. The more wiring, the more potential errors.

Material Unit Costs

Cost per Junction Box: Defaults are £16 for 1771/1746 Direct, £32 for Flex I/O (needs bigger box).

Incremental Cost of DeviceNet Device: defaults at £20 for adding the CAN chip to a device.

You may also adjust the following values:

- *Cost per Terminal Block*
- *Cost per ft. of Wire (14 AWG)*
- *Cost of 3/4 Inch Conduit, per foot*
- *Cost of 1 Inch Conduit, per foot*
- *Cost of 1-1/4 Inch Conduit, per foot*
- *Cost of 1-1/2 Inch Conduit, per foot*
- *Cost of 2 Inch Conduit, per foot*

Approximate I/O Cost (per point): This is an estimate that takes into account the cost of I/O modules, chassis, power supplies and adapter modules. You may want to adjust this number based on your experience or your customer's preferences. Typically small systems have a higher I/O cost per point than large systems. These are the default values:

- 1771/1746 I/O £18.00
- Flex I/O £12.00

Change the value in the 1771/1746 Direct column to £10.00 for 1746 (SLC-500) I/O.

Cost per DeviceNet Scanner: defaults at £400 approximate **nett** price. If there are two home runs from the same scanner, set this parameter to zero in the second homerun.

Cost of RIO or DeviceNet Cable per foot: defaults to 46 pence and 51 pence respectively.

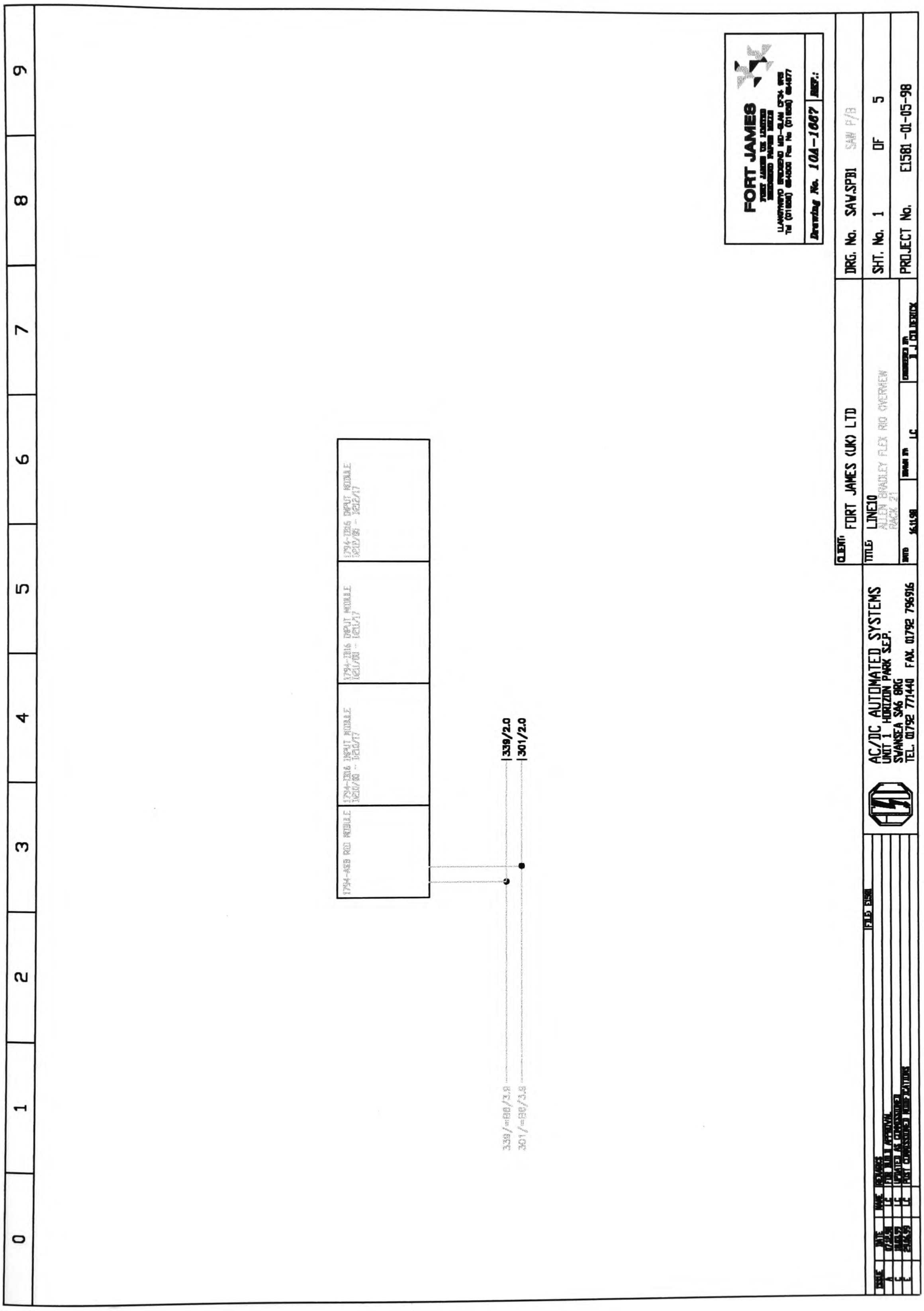
Cost of DeviceNet Connector, 1 tap: defaults to £29.00

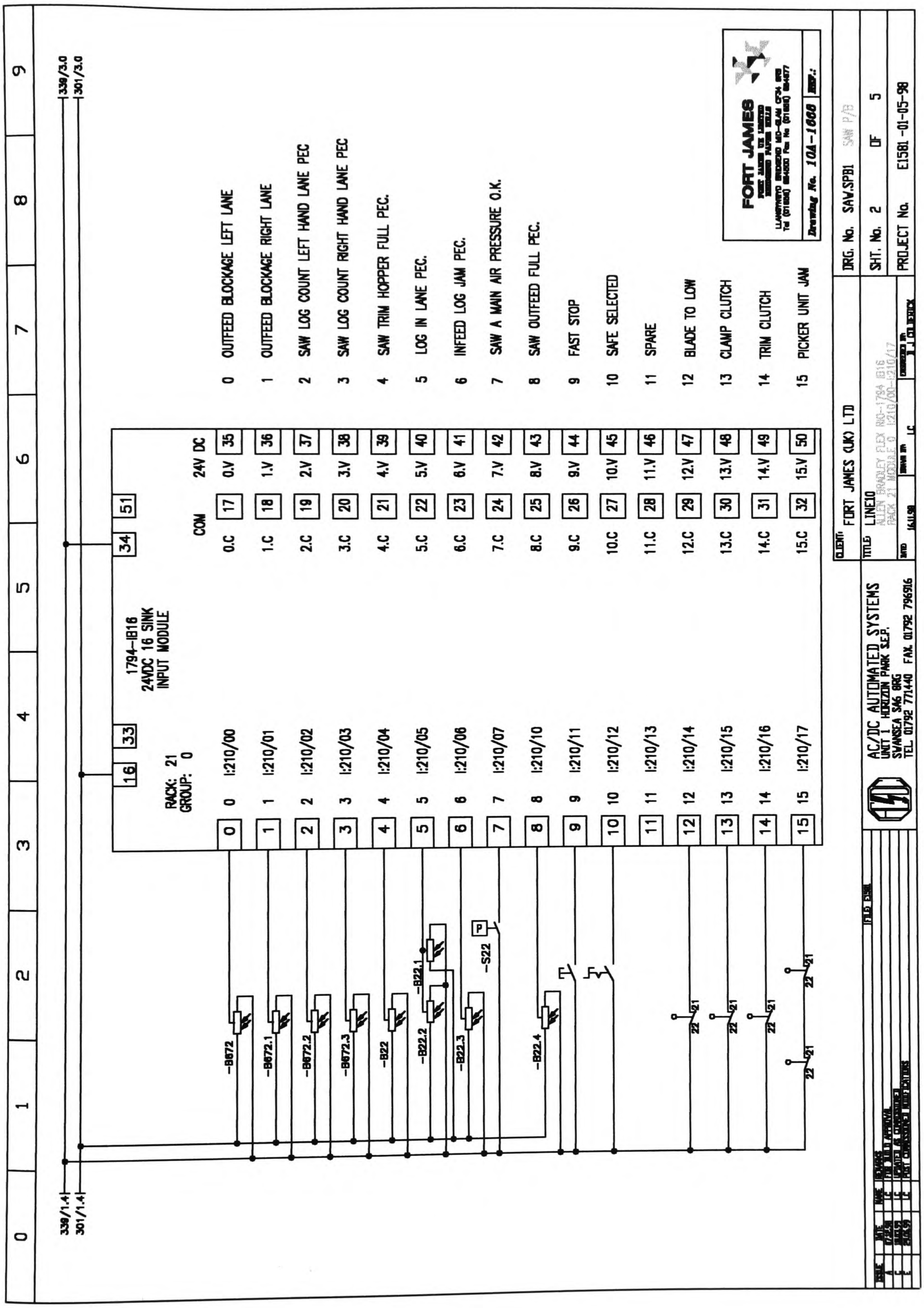
Cost of DeviceNet Connector, 8 tap: defaults to £108.00

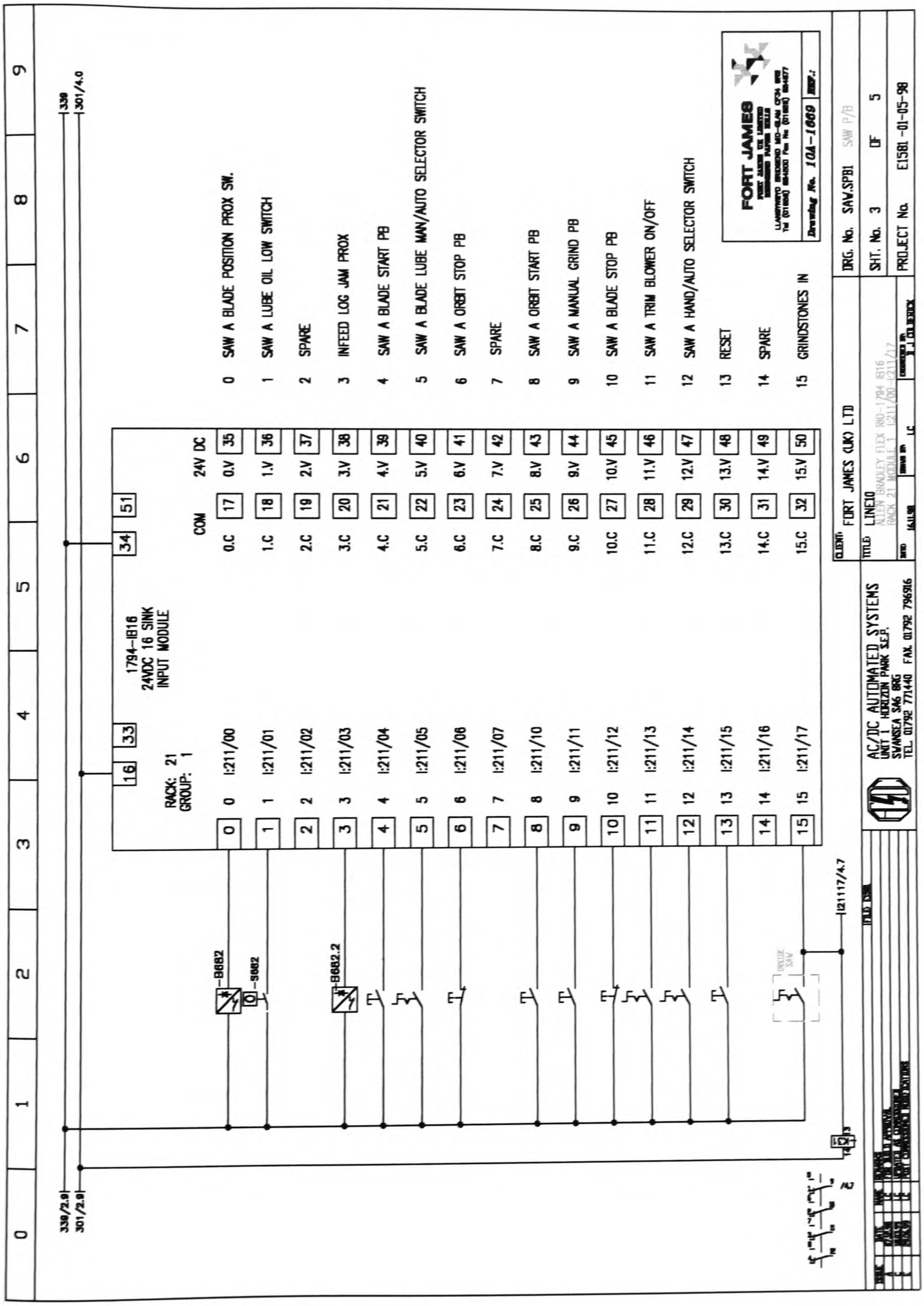
Saving changes

If you edit and want to save the new defaults, use "File Save As from the Excel menu to save your work under a unique filename. Clicking on the "Defaults" button will NOT restore all values to their default state; it only restores the device configuration entry table.

B.3 LINE 10 SAW I/O LISTINGS


FORT JAMES
Drawing No. 10A-1867
AC/DC AUTOMATED SYSTEMS
UNIT 1 HORIZON PARK SEP.
SWANSEA SA6 8RG
TEL. 01792 771440 FAX. 01792 796916
CLIENT: FORT JAMES (UK) LTD
TITLE: LINE10
DRG. No. SAW.SPB1
SHT. No. 1 OF 5
PROJECT No. E1581-01-05-98
339/2.0
301/2.0


1794-IB16
24VDC 16 SINK
INPUT MODULE
RACK: 21
GROUP: 0
COM
24V DC
I:210/00
I:210/01
I:210/02
I:210/03
I:210/04
I:210/05
I:210/06
I:210/07
I:210/10
I:210/11
I:210/12
I:210/13
I:210/14
I:210/15
I:210/16
I:210/17
0 OUTFEED BLOCKAGE LEFT LANE
1 OUTFEED BLOCKAGE RIGHT LANE
2 SAW LOG COUNT LEFT HAND LANE PEC
3 SAW LOG COUNT RIGHT HAND LANE PEC
4 SAW TRIM HOPPER FULL PEC.
5 LOG IN LANE PEC.
6 INFEED LOG JAM PEC.
7 SAW A MAIN AIR PRESSURE O.K.
8 SAW OUTFEED FULL PEC.
9 FAST STOP
10 SAFE SELECTED
11 SPARE
12 BLADE TO LOW
13 CLAMP CLUTCH
14 TRIM CLUTCH
15 PICKER UNIT JAM
-B672
-B672.1
-B672.2
-B672.3
-B22
-B22.1
-B22.2
-B22.3
-B22.4
-S22
338/1.4
301/1.4
338/3.0
301/3.0
FORT JAMES
AC/DC AUTOMATED SYSTEMS
UNIT 1 HORIZON PARK S.E.P.
SWANSEA SA6 8RG
TEL. 01792 771440 FAX. 01792 796916
CLIENT: FORT JAMES (UK) LTD
TITLE: LINE10
ALLEN BRADLEY FLEX I/O-1794 IB16
RACK 21 MODULE 0 I:210/00-I:210/17
DRG. No. SAV.SPB1
SHT. No. 2 OF 5
PROJECT No. E1581-01-05-98
Drawing No. 10A-1666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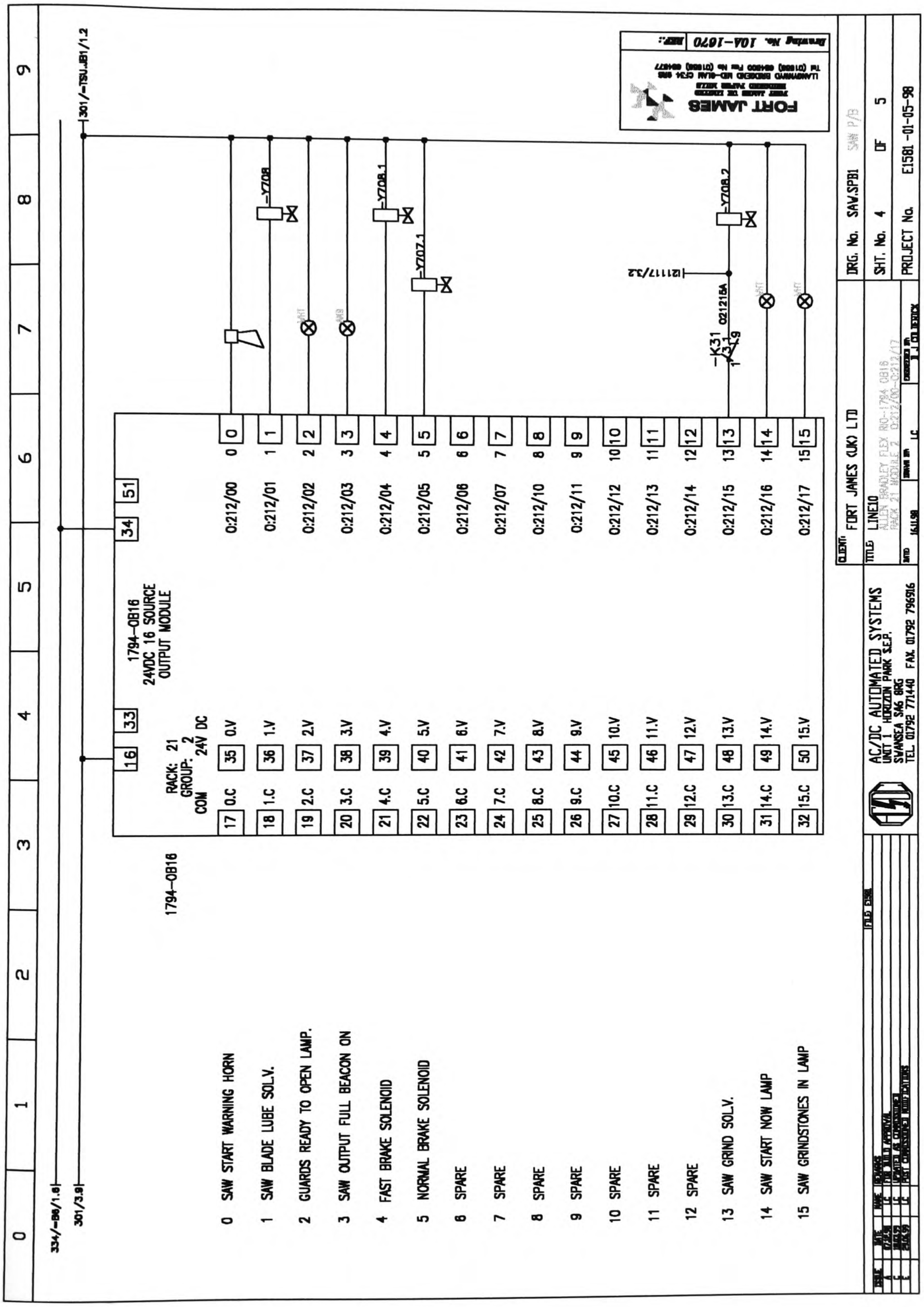
338/2.9
301/2.9
338
301/4.0
-B682
-S682
-B682.2
I21117/4.7
16 33 34 51
RACK: 21
GROUP: 1
1794-IB16
24VDC 16 SINK
INPUT MODULE
COM
24V DC
0 I:211/00 0.C 17 0.V 35 0 SAW A BLADE POSITION PROX SW.
1 I:211/01 1.C 18 1.V 36 1 SAW A LUBE OIL LOW SWITCH
2 I:211/02 2.C 19 2.V 37 2 SPARE
3 I:211/03 3.C 20 3.V 38 3 INFEED LOG JAM PROX
4 I:211/04 4.C 21 4.V 39 4 SAW A BLADE START PB
5 I:211/05 5.C 22 5.V 40 5 SAW A BLADE LUBE MAN/AUTO SELECTOR SWITCH
6 I:211/06 6.C 23 6.V 41 6 SAW A ORBIT STOP PB
7 I:211/07 7.C 24 7.V 42 7 SPARE
8 I:211/10 8.C 25 8.V 43 8 SAW A ORBIT START PB
9 I:211/11 9.C 26 9.V 44 9 SAW A MANUAL GRIND PB
10 I:211/12 10.C 27 10.V 45 10 SAW A BLADE STOP PB
11 I:211/13 11.C 28 11.V 46 11 SAW A TRIM BLOWER ON/OFF
12 I:211/14 12.C 29 12.V 47 12 SAW A HAND/AUTO SELECTOR SWITCH
13 I:211/15 13.C 30 13.V 48 13 RESET
14 I:211/16 14.C 31 14.V 49 14 SPARE
15 I:211/17 15.C 32 15.V 50 15 GRINDSTONES IN
FORT JAMES
Drawing No. 10A-1669
AC/DC AUTOMATED SYSTEMS
UNIT 1 HORIZON PARK S.E.P.
SWANSEA SA6 8RG
TEL. 01792 771440 FAX. 01792 796916
CLIENT: FORT JAMES (UK) LTD
TITLE: LINE10
DRG. No. SAW.SPB1
SHT. No. 3 OF 5
PROJECT No. E1581-01-05-98


1794–OB16
RACK: 21
GROUP: 2
COM 24V DC
1794–OB16
24VDC 16 SOURCE
OUTPUT MODULE
0 SAW START WARNING HORN
1 SAW BLADE LUBE SOL.V.
2 GUARDS READY TO OPEN LAMP.
3 SAW OUTPUT FULL BEACON ON
4 FAST BRAKE SOLENOID
5 NORMAL BRAKE SOLENOID
6 SPARE
7 SPARE
8 SPARE
9 SPARE
10 SPARE
11 SPARE
12 SPARE
13 SAW GRIND SOL.V.
14 SAW START NOW LAMP
15 SAW GRINDSTONES IN LAMP
-Y708
-Y708.1
-Y707.1
-Y708.2
-K31
FORT JAMES
Drawing No. 10A-1670
AC/DC AUTOMATED SYSTEMS
UNIT 1 HORIZON PARK S.E.P.
SWANSEA SA6 8RG
TEL. 01792 771440 FAX. 01792 796516
CLIENT: FORT JAMES (UK) LTD
TITLE: LINE10
DRG. No. SAV.SPB1
SHT. No. 4 OF 5
PROJECT No. E1581 -01-05-98

B.4 SAW COST ANALYSIS EXCLUDING PREMIUM

Saw Cost Analysis Excluding Premium

DEVICENET COST COMPARISON SOFTWARE

Version 4.00 With amendments by WD 09/04/01

NOTE: To protect against inadvertent changes, the spreadsheet is protected (no password). To turn off protection, use ***Tools*** menu.

HOMERUN CONFIGURATION ENTRY

Instructions:
Click one of the buttons above to view a sample configuration or restore the default data.

For each device in the homerun, please enter the distance from the head end of the homerun. Then enter the "Device Wire Equivalent" to indicate number of discrete signals. Default is 2-wire (representing 1 signal). e.g. :

Photcell/Proximity = 3 SMP-3 = 6
Redistation = 4 (3 signal and common)
Fex I/O (IB16/OB16) = 18 2705 = 7
Motor Drive =6 (start, stop, rev and ref)
Valves = no. of signals + ground

Note: *You may only enter data in cells colored* ***green*** *(unless you have turned off worksheet protection).*
Use ***FileSaveAs*** to save your configuration under a new file name.

Assumptions:
1771/1746 Direct Model
I/O in the central panel is wired to devices via conduit and junction boxes with terminal blocks. The toolkit assigns J.B.s according to the distance from the I/O panel and the max device cable length.

Homerun Wiring Data			
Device No.	Distance from Head End (ft.)	Device Wire Equivalent	Device Type
1	51.3	2	P.Button
2	51.3	2	Sel Sw
3	51.3	2	P.Button
4	51.3	2	Sel Sw
5	51.3	2	P.Button
6	51.3	2	P.Button
7	51.3	2	P.Button
8	51.3	2	P.Button
9	51.3	2	Sel Sw
10	51.3	2	Sel Sw
11	51.3	2	P.Button
12	51.3	2	Output
13	51.3	2	Output
14	51.3	2	Output
15	51.3	2	Output
16	60.3	2	Output
17	69.3	3	Valve
18	69.3	3	Valve
19	69.3	3	Valve
20	69.3	3	Valve
21	75.3	3	Photocell
22	75.3	3	Photocell
23	75.3	2	Press Sw
24	75.3	3	Lim Sw
25	75.3	3	Lim Sw
26	75.3	3	Lim Sw
27	75.3	3	Lim Sw
28	75.3	3	Proximity
29	75.3	2	Lim Sw
30	75.3	3	Proximity
31	75.3	2	Sel Sw
32	87.3	3	Photocell
33	87.3	3	Photocell

The "Approximate I/O Cost (per point)" value in the "Material Unit Cost" section below is £18.00 for 1771 (default). Change this value to £12.00 for 1746 (SLC) I/O.

Flex I/O Model
PLC processor is in central panel and Flex I/O is located in J.B.s. There are two runs of conduit from the central panel, one for power and one for RIO cable. The toolkit assigns J.B.s and Flex I/O based on distance from head end and max device cable length. Increase the max cable length to reduce number of Flex I/O blocks.

DeviceNet Model
DeviceNet scanner is in central panel. DeviceNet trunkline is run open, not in conduit. Each device connects via single or 8-point taps with a 10-ft. maximum dropline. You enter the number of 8-point taps in the "Measurements and Quantities" section below.

Adjusting Defaults
You may modify any default cost or configuration assumption that is displayed in a green cell, such as labour rate, spare capacity, etc.

34	87.3	3	Photocell
35	87.3	3	Photocell
36	87.3	3	Photocell
37	87.3	3	Photocell
38			
39			
40			
41			
42			
43			
44			
45			
46			
47			
48			
49			
50			
51			
52			
53			
54			
55			
56			
57			
58			
59			
60			
61			
62			
63			

	1771/1746 DIRECT	FLEX I/O	DEVICENET
Total Installed Cost (rounded to nearest £100.00)	£1,700	£1,200	£1,000

PREFERENCES ENTRY

	1771/1746 DIRECT	FLEX I/O	DEVICENET
SPARE CAPACITY			
Required Spare Capacity (Wires, I/O, T.B.)	20%	20%	20%
MEASUREMENTS & QUANTITIES			
Total Conduit or Trunkline Length (feet)	66	0	66
Maximum Device Cable Length (feet)	30	30	20
Qty. of Junction Boxes or Tap Locations	1	1	9
Total Number of Devices	37	37	37
Number of 8-point DeviceNet Taps			4
Input Points (per I/O card)	16	16	128
Are all wires terminated in each junction box?	n		
LABOUR UNIT COSTS			
Labour Time (minutes) per Connection:	1.2	1.2	1
Labour Rate (pounds per hour):	£23	£23	£23
Cost per ft. to install Conduit or Trunkline:	£1.20	£1.20	£0.90
Cost to Install Junction Box or Tap	£13	£13	£7
Estimated Rework Labour Percentage	10%	4%	2%
MATERIAL UNIT COSTS			
Cost per Junction Box	£16	£32	
Incremental Cost of DeviceNet Device	£0	£0	£0
Cost per Terminal Block	£1		
Cost per ft. of Wire (14 AWG)	£0.10		
Cost of 3/4 Inch Conduit, per foot	£1.00		
Cost of 1 Inch Conduit, per foot	£1.00		
Cost of 1-1/4 Inch Conduit, per foot	£1.00		
Cost of 1-1/2 Inch Conduit, per foot	£1.10		
Cost of 2 Inch Conduit, per foot	£1.24		
Approximate I/O Cost (per point)	£12	£12	
Cost per DeviceNet Scanner			£343
Cost of RIO or DeviceNet Cable per foot		£0.46	£0.37
Cost per DeviceNet Connector, 1 tap			£29.00
Cost per DeviceNet Connector, 8 tap			£93.00

	1771/1746 DIRECT	FLEX I/O	DEVICENET
INTERMEDIATE CALCULATIONS			
Feet of Power & Control Wire:	3788	133	
Feet of RIO or DeviceNet Cable Length:		67	68
Number ofTerminal Blocks:	68		
Number of DeviceNet Connectors, 1 tap:			5
Number of DeviceNet Connectors, 8 tap:			4
Number of I/O Connections:	76	80	5
Number of Flex I/O Adapters:		1	
Number of I/O or DeviceNet Scanner Cards:	5	5	1
LABOUR CALCULATIONS			
Wiring Labor Time (minutes):	255	192	60
Total Wiring Labour Cost:	£98	£74	£23
Labour Cost to Install Conduit:	£80	£0	£0
Labour Cost to Install DeviceNet Trunkline:			£60
Labour Cost to Install Junction Boxes:	£13	£13	£59
Total Labor Cost Before Rework:	£191	£87	£141
Cost to Rework Wiring Errors:	£19	£3	£3
Total Labor Cost	£210	£90	£144
MATERIAL CALCULATIONS			
Total Incremental Device Cost:	£0	£0	£0
Total Cost of Junction Boxes:	£16	£32	
Total DeviceNet Connector Cost:			£517
Total RIO or DeviceNet Cable Cost:		£0	£25
Total Terminal Block Cost:	£68		
Total Wire Cost:	£379	£13	
Estimated I/O Hardware Cost:	£960	£960	£343
Total Conduit Cost:	£66	£133	
Total Material Cost	£1,490	£1,138	£885

B.5 SAW COST ANALYSIS INCLUSIVE OF PREMIUM

Saw Cost Analysis Inclusive of Premium

DEVICENET COST COMPARISON SOFTWARE

Version 4.00 With amendments by WD 09/04/01

NOTE: To protect against inadvertent changes, the spreadsheet is protected (no password). To turn off protection, use ***Tools*** menu.

HOMERUN CONFIGURATION ENTRY

Instructions:
Click one of the buttons above to view a sample configuration or restore the default data.

For each device in the homerun, please enter the distance from the head end of the homerun.
Then enter the "Device Wire Equivalent" to indicate number of discrete signals. Default is 2-wire (representing 1 signal). e.g. :

Photcell/Proximity = 3 SMP-3 = 6
Redistation = 4 (3 signal and common)
Fex I/O (IB16/OB16) = 18 2705 = 7
Motor Drive =6 (start, stop, rev and ref)
Valves = no. of signals + ground

Note: *You may only enter data in cells colored* ***green*** *(unless you have turned off worksheet protection).*
Use ***FileSaveAs*** to save your configuration under a new file name.

Assumptions:
1771/1746 Direct Model
I/O in the central panel is wired to devices via conduit and junction boxes with terminal blocks. The toolkit assigns J.B.s according to the distance from the I/O panel and the max device cable length.

Homerun Wiring Data			
Device No.	Distance from Head End (ft.)	Device Wire Equivalent	Device Type
1	51.3	2	P.Button
2	51.3	2	Sel Sw
3	51.3	2	P.Button
4	51.3	2	Sel Sw
5	51.3	2	P.Button
6	51.3	2	P.Button
7	51.3	2	P.Button
8	51.3	2	P.Button
9	51.3	2	Sel Sw
10	51.3	2	Sel Sw
11	51.3	2	P.Button
12	51.3	2	Output
13	51.3	2	Output
14	51.3	2	Output
15	51.3	2	Output
16	60.3	2	Output
17	69.3	3	Valve
18	69.3	3	Valve
19	69.3	3	Valve
20	69.3	3	Valve
21	75.3	3	Photocell
22	75.3	3	Photocell
23	75.3	2	Press Sw
24	75.3	3	Lim Sw
25	75.3	3	Lim Sw
26	75.3	3	Lim Sw
27	75.3	3	Lim Sw
28	75.3	3	Proximity
29	75.3	2	Lim Sw
30	75.3	3	Proximity
31	75.3	2	Sel Sw
32	87.3	3	Photocell
33	87.3	3	Photocell

The "Approximate I/O Cost (per point)" value in the "Material Unit Cost" section below is £18.00 for 1771 (default). Change this value to £12.00 for 1746 (SLC) I/O.

Flex I/O Model

PLC processor is in central panel and Flex I/O is located in J.B.s. There are two runs of conduit from the central panel, one for power and one for RIO cable. The toolkit assigns J.B.s and Flex I/O based on distance from head end and max device cable length. Increase the max cable length to reduce number of Flex I/O blocks.

DeviceNet Model

DeviceNet scanner is in central panel. DeviceNet trunkline is run open, not in conduit. Each device connects via single or 8-point taps with a 10-ft. maximum dropline. You enter the number of 8-point taps in the "Measurements and Quantities" section below.

Adjusting Defaults

You may modify any default cost or configuration assumption that is displayed in a green cell, such as labour rate, spare capacity, etc.

34	87.3	3	Photocell
35	87.3	3	Photocell
36	87.3	3	Photocell
37	87.3	3	Photocell
38			
39			
40			
41			
42			
43			
44			
45			
46			
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56			
57			
58			
59			
60			
61			
62			
63			

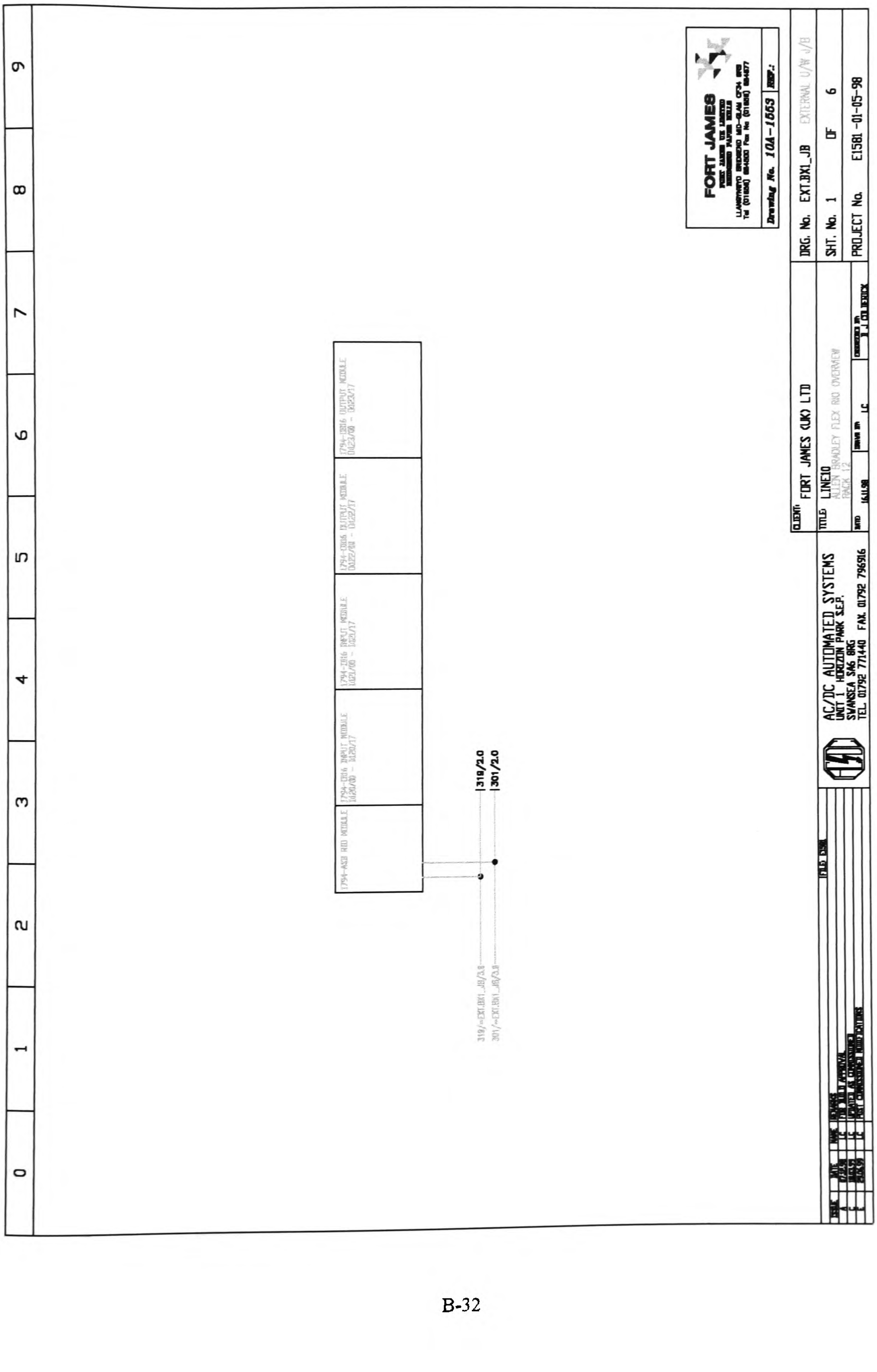
	1771/1746 DIRECT	FLEX I/O	DEVICENET
Total Installed Cost (rounded to nearest £100.00)	£1,700	£1,200	£2,000

PREFERENCES ENTRY

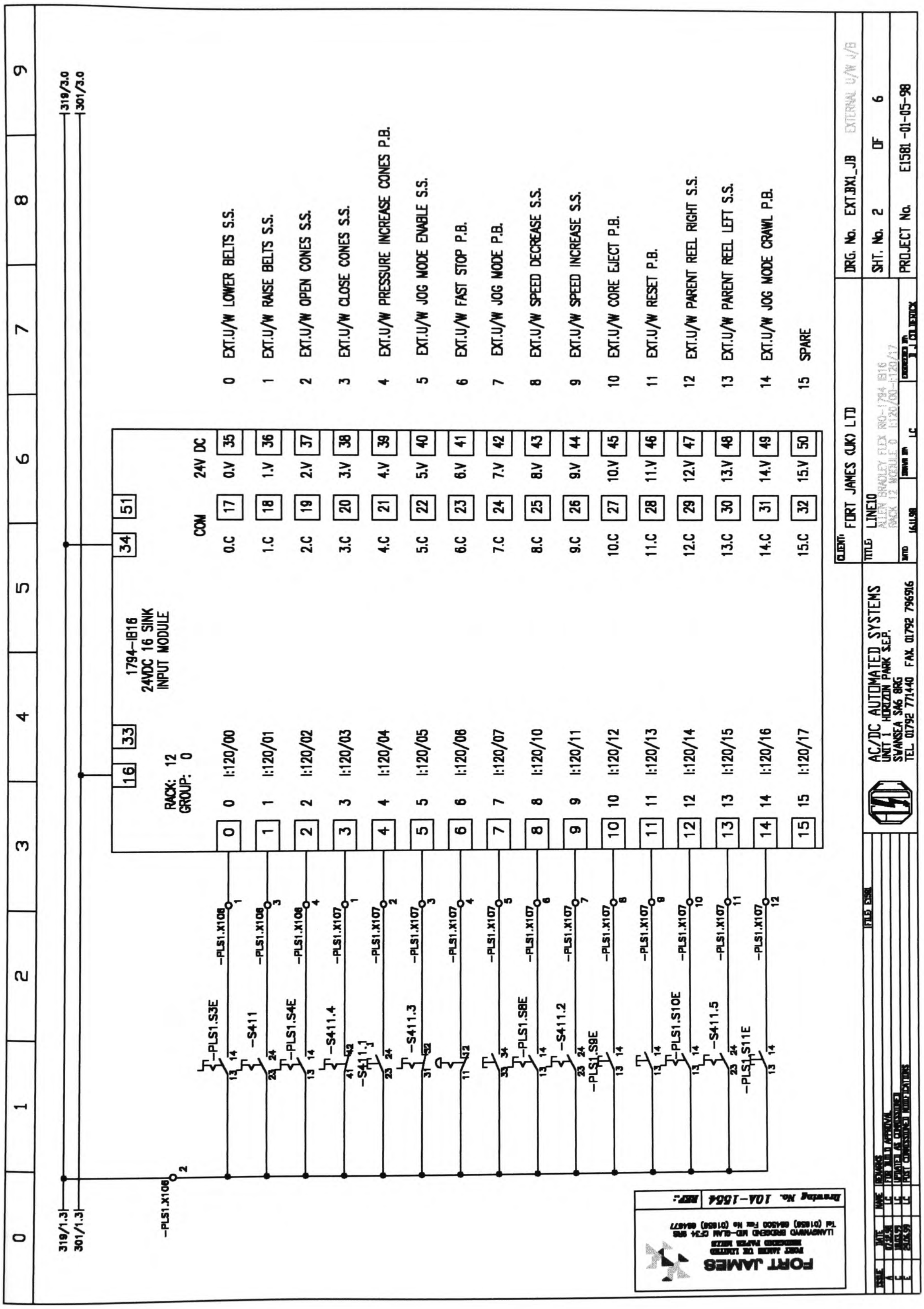
	1771/1746 DIRECT	FLEX I/O	DEVICENET
SPARE CAPACITY			
Required Spare Capacity (Wires, I/O, T.B.)	20%	20%	20%
MEASUREMENTS & QUANTITIES			
Total Conduit or Trunkline Length (feet)	66	0	66
Maximum Device Cable Length (feet)	30	30	20
Qty. of Junction Boxes or Tap Locations	1	1	9
Total Number of Devices	37	37	37
Number of 8-point DeviceNet Taps			4
Input Points (per I/O card)	16	16	128
Are all wires terminated in each junction box?	n		
LABOUR UNIT COSTS			
Labour Time (minutes) per Connection:	1.2	1.2	1
Labour Rate (pounds per hour):	£23	£23	£23
Cost per ft. to install Conduit or Trunkline:	£1.20	£1.20	£0.90
Cost to Install Junction Box or Tap	£13	£13	£7
Estimated Rework Labour Percentage	10%	4%	2%
MATERIAL UNIT COSTS			
Cost per Junction Box	£16	£32	
Incremental Cost of DeviceNet Device	£0	£0	£25
Cost per Terminal Block	£1		
Cost per ft. of Wire (14 AWG)	£0.10		
Cost of 3/4 Inch Conduit, per foot	£1.00		
Cost of 1 Inch Conduit, per foot	£1.00		
Cost of 1-1/4 Inch Conduit, per foot	£1.00		
Cost of 1-1/2 Inch Conduit, per foot	£1.10		
Cost of 2 Inch Conduit, per foot	£1.24		
Approximate I/O Cost (per point)	£12	£12	
Cost per DeviceNet Scanner			£343
Cost of RIO or DeviceNet Cable per foot		£0.46	£0.37
Cost per DeviceNet Connector, 1 tap			£29.00
Cost per DeviceNet Connector, 8 tap			£93.00

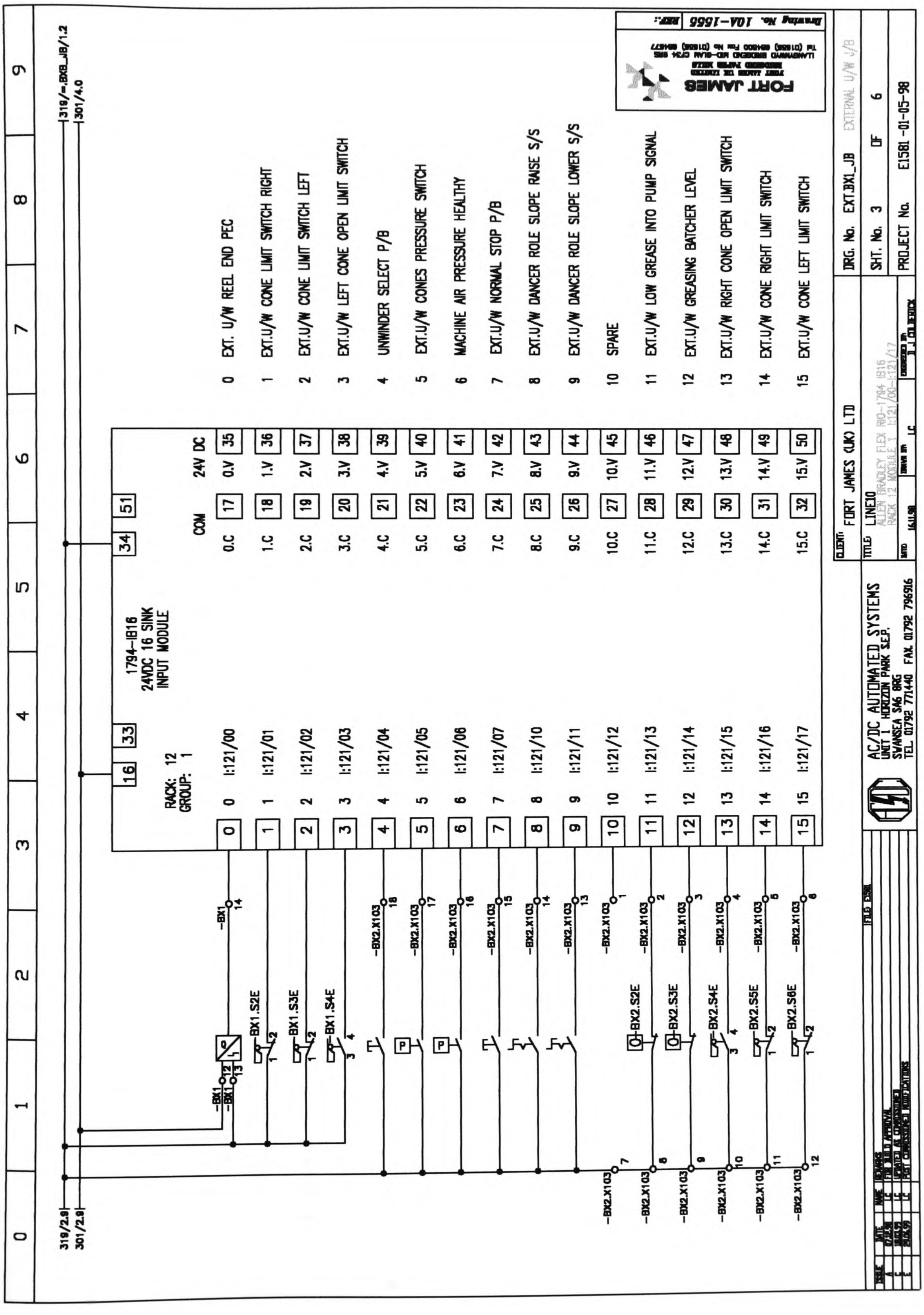
	1771/1746 DIRECT	FLEX I/O	DEVICENET
INTERMEDIATE CALCULATIONS			
Feet of Power & Control Wire:	3788	133	
Feet of RIO or DeviceNet Cable Length:		67	68
Number ofTerminal Blocks:	68		
Number of DeviceNet Connectors, 1 tap:			5
Number of DeviceNet Connectors, 8 tap:			4
Number of I/O Connections:	76	80	5
Number of Flex I/O Adapters:		1	
Number of I/O or DeviceNet Scanner Cards:	5	5	1
LABOUR CALCULATIONS			
Wiring Labor Time (minutes):	255	192	60
Total Wiring Labour Cost:	£98	£74	£23
Labour Cost to Install Conduit:	£80	£0	£0
Labour Cost to Install DeviceNet Trunkline:			£60
Labour Cost to Install Junction Boxes:	£13	£13	£59
Total Labor Cost Before Rework:	£191	£87	£141
Cost to Rework Wiring Errors:	£19	£3	£3
Total Labor Cost	£210	£90	£144
MATERIAL CALCULATIONS			
Total Incremental Device Cost:	£0	£0	£925
Total Cost of Junction Boxes:	£16	£32	
Total DeviceNet Connector Cost:			£517
Total RIO or DeviceNet Cable Cost:		£0	£25
Total Terminal Block Cost:	£68		
Total Wire Cost:	£379	£13	
Estimated I/O Hardware Cost:	£960	£960	£343
Total Conduit Cost:	£66	£133	
Total Material Cost	£1,490	£1,138	£1,810

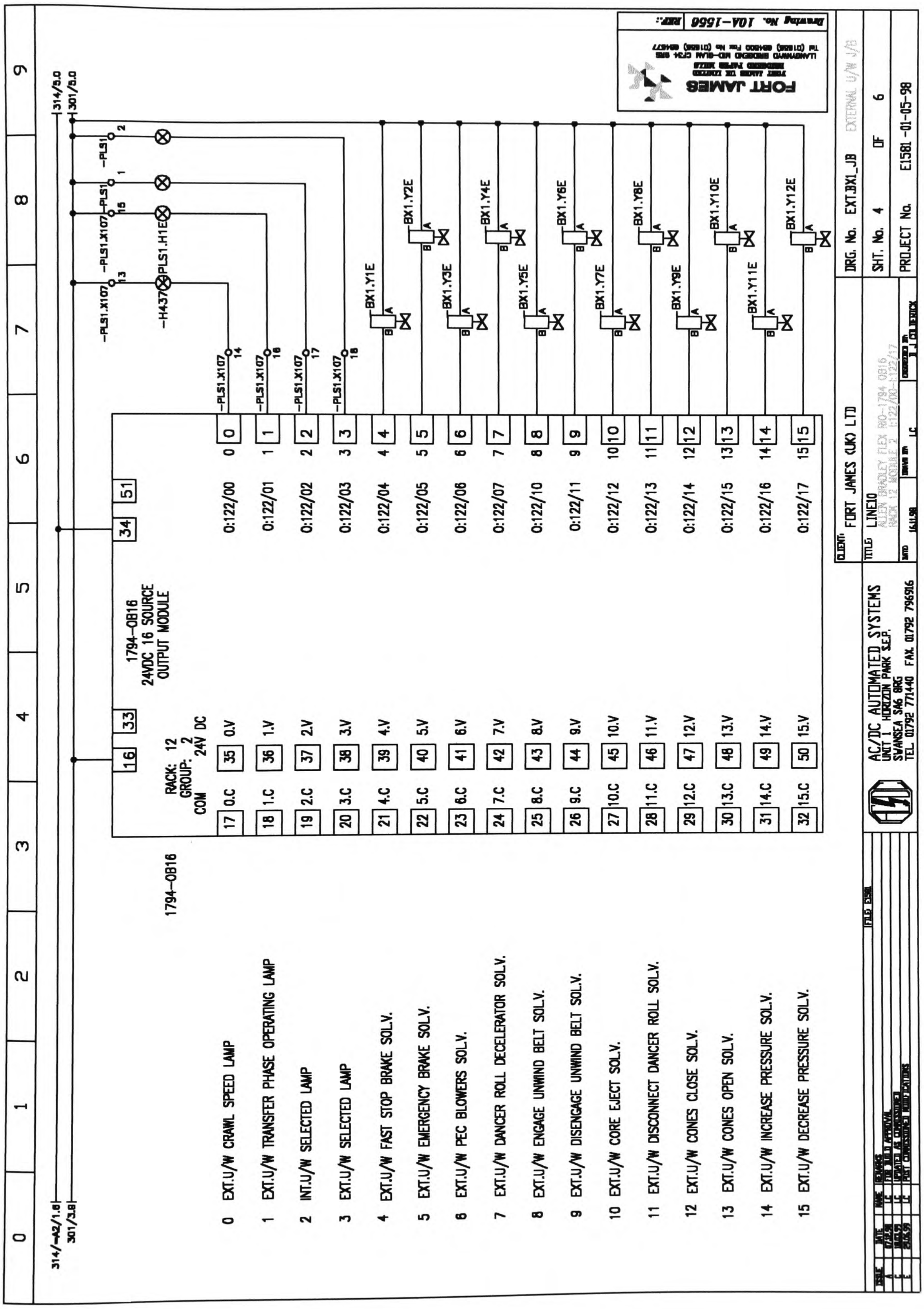
B.6 LINE 10 EXTERNAL UNWIND I/O LISTINGS

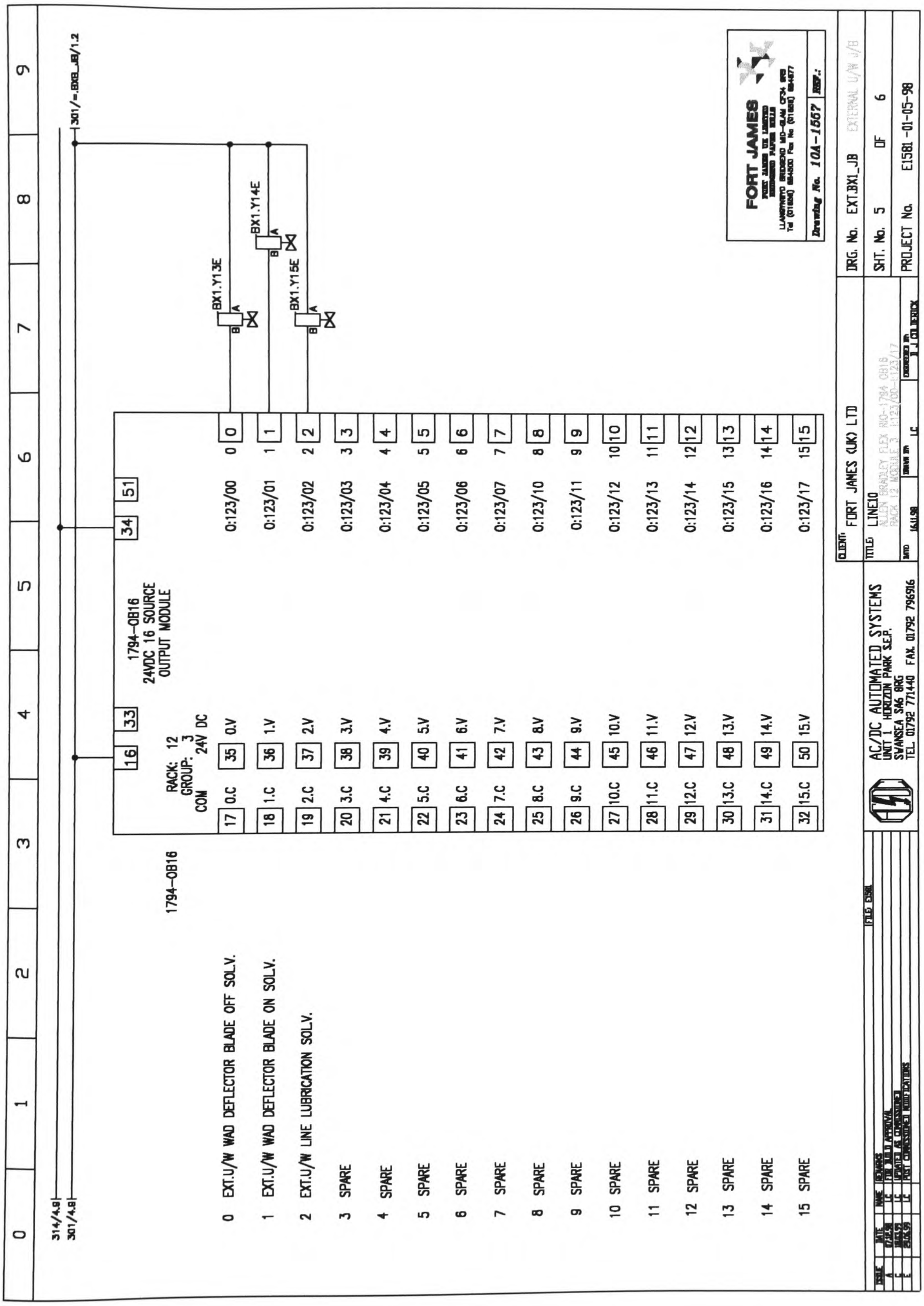


FORT JAMES
Drawing No. 10A-1553
DRG. No. EXT.BX1_JB
SHT. No. 1 OF 6
PROJECT No. E1581-01-05-98
CLIENT: FORT JAMES (UK) LTD
TITLE: LINE10
AC/DC AUTOMATED SYSTEMS
UNIT 1, HORIZON PARK S.E.P.
SWANSEA SA6 8RG
TEL. 01792 771440 FAX. 01792 796916
319/2.0
301/2.0

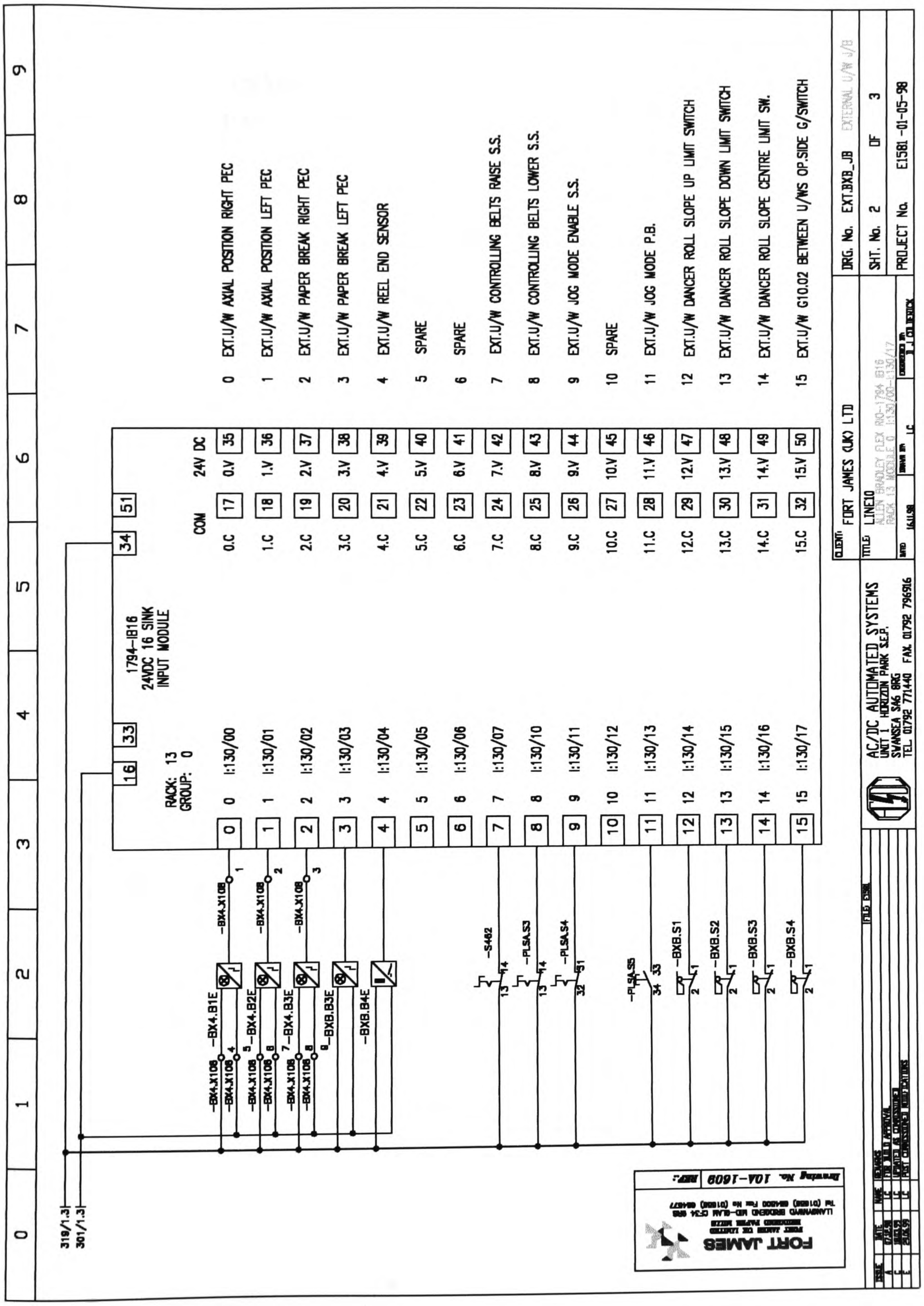

1794-IB16
24VDC 16 SINK
INPUT MODULE
RACK: 12
GROUP: 0
COM
24V DC
0 EXT.U/W LOWER BELTS S.S.
1 EXT.U/W RAISE BELTS S.S.
2 EXT.U/W OPEN CONES S.S.
3 EXT.U/W CLOSE CONES S.S.
4 EXT.U/W PRESSURE INCREASE CONES P.B.
5 EXT.U/W JOG MODE ENABLE S.S.
6 EXT.U/W FAST STOP P.B.
7 EXT.U/W JOG MODE P.B.
8 EXT.U/W SPEED DECREASE S.S.
9 EXT.U/W SPEED INCREASE S.S.
10 EXT.U/W CORE EJECT P.B.
11 EXT.U/W RESET P.B.
12 EXT.U/W PARENT REEL RIGHT S.S.
13 EXT.U/W PARENT REEL LEFT S.S.
14 EXT.U/W JOG MODE CRAWL P.B.
15 SPARE
AC/DC AUTOMATED SYSTEMS
CLIENT: FORT JAMES (UK) LTD
TITLE: LINEIO
DRG. No. EXT.BX1_JB
SHT. No. 2 OF 6
PROJECT No. E1581-01-05-98
FORT JAMES


0 1 2 3 4 5 6 7 8 9
319/2.9
301/2.9
319/=.BX8_JB/1.2
301/4.0
RACK: 12
GROUP: 1
1794-IB16
24VDC 16 SINK
INPUT MODULE
COM
24V DC
0 EXT. U/W REEL END PEC
1 EXT.U/W CONE LIMIT SWITCH RIGHT
2 EXT.U/W CONE LIMIT SWITCH LEFT
3 EXT.U/W LEFT CONE OPEN LIMIT SWITCH
4 UNWINDER SELECT P/B
5 EXT.U/W CONES PRESSURE SWITCH
6 MACHINE AIR PRESSURE HEALTHY
7 EXT.U/W NORMAL STOP P/B
8 EXT.U/W DANCER ROLE SLOPE RAISE S/S
9 EXT.U/W DANCER ROLE SLOPE LOWER S/S
10 SPARE
11 EXT.U/W LOW GREASE INTO PUMP SIGNAL
12 EXT.U/W GREASING BATCHER LEVEL
13 EXT.U/W RIGHT CONE OPEN LIMIT SWITCH
14 EXT.U/W CONE RIGHT LIMIT SWITCH
15 EXT.U/W CONE LEFT LIMIT SWITCH
AC/DC AUTOMATED SYSTEMS
UNIT 1 HORIZON PARK S.E.P.
SWANSEA SA6 8RG
TEL. 01792 771440 FAX. 01792 796916
CLIENT: FORT JAMES (UK) LTD
TITLE: LINE10
ALLEN BRADLEY FLEX RIO-1794 IB16
RACK 12 MODULE 1 I:121/00-I:121/17
DRG. No. EXT.BX1_JB
SHT. No. 3 OF 6
PROJECT No. E1581-01-05-98
EXTERNAL U/W J/B
FORT JAMES
Drawing No. 10A-1555


0 EXT.U/W CRAWL SPEED LAMP
1 EXT.U/W TRANSFER PHASE OPERATING LAMP
2 INT.U/W SELECTED LAMP
3 EXT.U/W SELECTED LAMP
4 EXT.U/W FAST STOP BRAKE SOL.V.
5 EXT.U/W EMERGENCY BRAKE SOL.V.
6 EXT.U/W PEC BLOWERS SOL.V.
7 EXT.U/W DANCER ROLL DECELERATOR SOL.V.
8 EXT.U/W ENGAGE UNWIND BELT SOL.V.
9 EXT.U/W DISENGAGE UNWIND BELT SOL.V.
10 EXT.U/W CORE EJECT SOL.V.
11 EXT.U/W DISCONNECT DANCER ROLL SOL.V.
12 EXT.U/W CONES CLOSE SOL.V.
13 EXT.U/W CONES OPEN SOL.V.
14 EXT.U/W INCREASE PRESSURE SOL.V.
15 EXT.U/W DECREASE PRESSURE SOL.V.
1794-OB16
RACK: 12
GROUP: 2
COM 24V DC
1794-OB16
24VDC 16 SOURCE
OUTPUT MODULE
O:122/00
O:122/01
O:122/02
O:122/03
O:122/04
O:122/05
O:122/06
O:122/07
O:122/10
O:122/11
O:122/12
O:122/13
O:122/14
O:122/15
O:122/16
O:122/17
314/-A2/1.8
301/3.8
314/9.0
301/9.0
-PLS1.X107
-H437
-PLS1.H1E
-PLS1
BX1.Y1E
BX1.Y2E
BX1.Y3E
BX1.Y4E
BX1.Y5E
BX1.Y6E
BX1.Y7E
BX1.Y8E
BX1.Y9E
BX1.Y10E
BX1.Y11E
BX1.Y12E
AC/DC AUTOMATED SYSTEMS
UNIT 1 HORIZON PARK S.E.P.
SWANSEA SA6 8RG
TEL. 01792 771440 FAX. 01792 796916
CLIENT: FORT JAMES (UK) LTD
TITLE: LINE10
ALLEN BRADLEY FLEX RIO-1794 OB16
RACK 12 MODULE 2 O:122/00-O:122/17
DRG. No. EXT.BX1_JB EXTERNAL U/W J/B
SHT. No. 4 OF 6
PROJECT No. E1581-01-05-98
FORT JAMES
Drawing No. 10A-1556



0 EXT.U/W WAD DEFLECTOR BLADE OFF SOLV.
1 EXT.U/W WAD DEFLECTOR BLADE ON SOLV.
2 EXT.U/W LINE LUBRICATION SOLV.
3 SPARE
4 SPARE
5 SPARE
6 SPARE
7 SPARE
8 SPARE
9 SPARE
10 SPARE
11 SPARE
12 SPARE
13 SPARE
14 SPARE
15 SPARE
1794-OB16
RACK: 12
GROUP: 3
COM 24V DC
1794-OB16
24VDC 16 SOURCE
OUTPUT MODULE
BX1.Y13E
BX1.Y14E
BX1.Y15E
FORT JAMES
Drawing No. 10A-1557
AC/DC AUTOMATED SYSTEMS
UNIT 1 HORIZON PARK S.E.P.
SWANSEA SA6 8RG
TEL 01792 771440 FAX 01792 796916
CLIENT: FORT JAMES (UK) LTD
TITLE: LINE10
DRG. No. EXT.BX1_JB
SHT. No. 5 OF 6
PROJECT No. E1581-01-05-98


1794-IB16
24VDC 16 SINK
INPUT MODULE
RACK: 13
GROUP: 0
COM
24V DC
0 EXT.U/W AXIAL POSITION RIGHT PEC
1 EXT.U/W AXIAL POSITION LEFT PEC
2 EXT.U/W PAPER BREAK RIGHT PEC
3 EXT.U/W PAPER BREAK LEFT PEC
4 EXT.U/W REEL END SENSOR
5 SPARE
6 SPARE
7 EXT.U/W CONTROLLING BELTS RAISE S.S.
8 EXT.U/W CONTROLLING BELTS LOWER S.S.
9 EXT.U/W JOG MODE ENABLE S.S.
10 SPARE
11 EXT.U/W JOG MODE P.B.
12 EXT.U/W DANCER ROLL SLOPE UP LIMIT SWITCH
13 EXT.U/W DANCER ROLL SLOPE DOWN LIMIT SWITCH
14 EXT.U/W DANCER ROLL SLOPE CENTRE LIMIT SW.
15 EXT.U/W G10.02 BETWEEN U/WS OP.SIDE G/SWITCH
I:130/00
I:130/01
I:130/02
I:130/03
I:130/04
I:130/05
I:130/06
I:130/07
I:130/10
I:130/11
I:130/12
I:130/13
I:130/14
I:130/15
I:130/16
I:130/17
-BX4.B1E
-BX4.B2E
-BX4.B3E
-BXB.B3E
-BXB.B4E
-BX4.X108
-S482
-PLSA.S3
-PLSA.S4
-PLSA.S5
-BXB.S1
-BXB.S2
-BXB.S3
-BXB.S4
319/1.3
301/1.3
AC/DC AUTOMATED SYSTEMS
UNIT 1 HORIZON PARK S.E.P.
SWANSEA SA6 8RG
TEL 01792 771440 FAX 01792 796516
CLIENT: FORT JAMES (UK) LTD
TITLE LINE10
ALLEN BRADLEY FLEX RIO-1794 IB16
RACK 13 MODULE 0 I:130/00-I:130/17
DRG. No. EXT.BXB_JB EXTERNAL U/W J/B
SHT. No. 2 OF 3
PROJECT No. E1581-01-05-98
FORT JAMES
Drawing No. 10A-1609

B.7 UNWIND COST ANALYSIS EXCLUDING PREMIUM

Unwind Cost Analysis Excluding Premium

DEVICENET COST COMPARISON SOFTWARE

Version 4.00 With amendments by WD 09/04/01

NOTE: To protect against inadvertent changes, the spreadsheet is protected (no password). To turn off protection, use ***Tools*** menu.

HOMERUN CONFIGURATION ENTRY

Instructions:
Click one of the buttons above to view a sample configuration or restore the default data.

For each device in the homerun, please enter the distance from the head end of the homerun. Then enter the "Device Wire Equivalent" to indicate number of discrete signals. Default is 2-wire (representing 1 signal). e.g. :

Photcell/Proximity = 3 SMP-3 = 6
Redistation = 4 (3 signal and common)
Fex I/O (IB16/OB16) = 18 2705 = 7
Motor Drive =6 (start, stop, rev and ref)
Valves = no. of signals + ground

Note: *You may only enter data in cells colored* ***green*** *(unless you have turned off worksheet protection).*
Use ***FileSaveAs*** to save your configuration under a new file name.

Assumptions:
1771/1746 Direct Model
I/O in the central panel is wired to devices via conduit and junction boxes with terminal blocks. The toolkit assigns J.B.s according to the distance from the I/O panel and

Homerun Wiring Data			
Device No.	Distance from Head End (ft.)	Device Wire Equivalent	Device Type
1	105	2	Sel Sw
2	105	2	Sel Sw
3	105	2	Sel Sw
4	105	2	Sel Sw
5	105	2	P.Button
6	105	2	Sel Sw
7	105	2	Sel Sw
8	105	2	P.Button
9	105	2	P.Button
10	105	2	Sel Sw
11	105	2	Sel Sw
12	105	2	P.Button
13	105	2	P.Button
14	105	2	Sel Sw
15	105	2	Sel Sw
16	105	2	P.Button
17	105	3	Photo
18	105	2	Lim Sw
19	105	2	Lim Sw
20	105	2	Lim Sw
21	105	2	Lim Sw
22	105	2	P.Button
23	105	2	Pres Sw
24	105	2	Pres Sw
25	105	2	P.Button
26	105	2	Sel Sw
27	105	2	Sel Sw
28	105	2	Lim Sw
29	105	2	Lim Sw
30	105	2	Lim Sw
31	105	2	Lim Sw
32	105	2	Lim Sw

The "Approximate I/O Cost (per point)" value in the "Material Unit Cost" section below is £18.00 for 1771 (default). Change this value to £12.00 for 1746 (SLC) I/O.

Flex I/O Model

PLC processor is in central panel and Flex I/O is located in J.B.s. There are two runs of conduit from the central panel, one for power and one for RIO cable. The toolkit assigns J.B.s and Flex I/O based on distance from head end and max device cable length. Increase the max cable length to reduce number of Flex I/O blocks.

DeviceNet Model

DeviceNet scanner is in central panel. DeviceNet trunkline is run open, not in conduit. Each device connects via single or 8-point taps with a 10-ft. maximum dropline. You enter the number of 8-point taps in the "Measurements and Quantities" section below.

Adjusting Defaults

You may modify any default cost or configuration assumption that is displayed in a green cell, such as labour rate, spare capacity, etc.

34	105	2	Lamp
35	105	2	Lamp
36	105	2	Lamp
37	115	2	Valve
38	115	3	Valve
39	115	3	Valve
40	115	3	Valve
41	115	3	Valve
42	115	3	Valve
43	115	3	Valve
44	115	3	Valve
45	115	3	Valve
46	115	3	Valve
47	115	3	Valve
48	115	3	Valve
49	115	3	Valve
50	115	3	Valve
51	115	3	Valve
52	122	3	Photo
53	122	3	Photo
54	122	3	Photo
55	122	3	Photo
56	122	3	Photo
57	122	2	Sel Sw
58	122	2	Sel Sw
59	122	2	Sel Sw
60	122	2	P.Button
61	122	2	Lim Sw
62	122	2	Lim Sw
63	122	2	Lim Sw

	1771/1746 DIRECT	FLEX I/O	DEVICENET
Total Installed Cost (rounded to nearest £100.00)	£2,800	£1,700	£1,500

PREFERENCES ENTRY	1771/1746 DIRECT	FLEX I/O	DEVICENET
SPARE CAPACITY			
Required Spare Capacity (Wires, I/O, T.B.)	20%	20%	20%
MEASUREMENTS & QUANTITIES			
Total Conduit or Trunkline Length (feet)	111	0	111
Maximum Device Cable Length (feet)	30	30	20
Qty. of Junction Boxes or Tap Locations	1	1	14
Total Number of Devices	63	63	63
Number of 8-point DeviceNet Taps			7
Input Points (per I/O card)	16	16	128
Are all wires terminated in each junction box?	y		
LABOUR UNIT COSTS			
Labour Time (minutes) per Connection:	1.2	1.2	1
Labour Rate (pounds per hour):	£23	£23	£23
Cost per ft. to install Conduit or Trunkline:	£1.20	£1.20	£0.90
Cost to Install Junction Box or Tap	£13	£13	£7
Estimated Rework Labour Percentage	10%	4%	2%
MATERIAL UNIT COSTS			
Cost per Junction Box	£16	£32	
Incremental Cost of DeviceNet Device	£0	£0	£0
Cost per Terminal Block	£1		
Cost per ft. of Wire (14 AWG)	£0.10		
Cost of 3/4 Inch Conduit, per foot	£1.00		
Cost of 1 Inch Conduit, per foot	£1.00		
Cost of 1-1/4 Inch Conduit, per foot	£1.00		
Cost of 1-1/2 Inch Conduit, per foot	£1.10		
Cost of 2 Inch Conduit, per foot	£1.24		
Approximate I/O Cost (per point)	£12	£12	
Cost per DeviceNet Scanner			£343
Cost of RIO or DeviceNet Cable per foot		£0.46	£0.37
Cost per DeviceNet Connector, 1 tap			£29.00
Cost per DeviceNet Connector, 8 tap			£93.00

	1771/1746 DIRECT	FLEX I/O	DEVICENET
INTERMEDIATE CALCULATIONS			
Feet of Power & Control Wire:	9403	221	
Feet of RIO or DeviceNet Cable Length:		112	113
Number ofTerminal Blocks:	102		
Number of DeviceNet Connectors, 1 tap:			7
Number of DeviceNet Connectors, 8 tap:			7
Number of I/O Connections:	114	118	5
Number of Flex I/O Adapters:		1	
Number of I/O or DeviceNet Scanner Cards:	7	7	1
LABOUR CALCULATIONS			
Wiring Labor Time (minutes):	381	282	96
Total Wiring Labour Cost:	£146	£108	£37
Labour Cost to Install Conduit:	£133	£0	£0
Labour Cost to Install DeviceNet Trunkline:			£100
Labour Cost to Install Junction Boxes:	£13	£13	£91
Total Labor Cost Before Rework:	£292	£121	£227
Cost to Rework Wiring Errors:	£29	£5	£5
Total Labor Cost	£321	£126	£232
MATERIAL CALCULATIONS			
Total Incremental Device Cost:	£0	£0	£0
Total Cost of Junction Boxes:	£16	£32	
Total DeviceNet Connector Cost:			£854
Total RIO or DeviceNet Cable Cost:		£0	£41
Total Terminal Block Cost:	£102		
Total Wire Cost:	£940	£22	
Estimated I/O Hardware Cost:	£1,344	£1,344	£343
Total Conduit Cost:	£122	£221	
Total Material Cost	£2,524	£1,619	£1,238

B.8 UNWIND COST ANALYSIS INCLUSIVE OF PREMIUM

Unwind Cost Analysis Inclusive of Premium

DEVICENET COST COMPARISON SOFTWARE

Version 4.00 With amendments by WD 09/04/01

NOTE: To protect against inadvertent changes, the spreadsheet is protected (no password). To turn off protection, use ***Tools*** menu.

HOMERUN CONFIGURATION ENTRY

Instructions:
Click one of the buttons above to view a sample configuration or restore the default data.

For each device in the homerun, please enter the distance from the head end of the homerun. Then enter the "Device Wire Equivalent" to indicate number of discrete signals. Default is 2-wire (representing 1 signal). e.g. :

Photocell/Proximity = 3 SMP-3 = 6
Redistation = 4 (3 signal and common)
Fex I/O (IB16/OB16) = 18 2705 = 7
Motor Drive =6 (start, stop, rev and ref)
Valves = no. of signals + ground

Note: *You may only enter data in cells colored* ***green*** *(unless you have turned off worksheet protection).*
Use ***FileSaveAs*** to save your configuration under a new file name.

Assumptions:
1771/1746 Direct Model
I/O in the central panel is wired to devices via conduit and junction boxes with terminal blocks. The toolkit assigns J.B.s according to the distance from the I/O panel and the max device cable length.

Homerun Wiring Data			
Device No.	Distance from Head End (ft.)	Device Wire Equivalent	Device Type
1	105	2	Sel Sw
2	105	2	Sel Sw
3	105	2	Sel Sw
4	105	2	Sel Sw
5	105	2	P.Button
6	105	2	Sel Sw
7	105	2	Sel Sw
8	105	2	P.Button
9	105	2	P.Button
10	105	2	Sel Sw
11	105	2	Sel Sw
12	105	2	P.Button
13	105	2	P.Button
14	105	2	Sel Sw
15	105	2	Sel Sw
16	105	2	P.Button
17	105	3	Photo
18	105	2	Lim Sw
19	105	2	Lim Sw
20	105	2	Lim Sw
21	105	2	Lim Sw
22	105	2	P.Button
23	105	2	Pres Sw
24	105	2	Pres Sw
25	105	2	P.Button
26	105	2	Sel Sw
27	105	2	Sel Sw
28	105	2	Lim Sw
29	105	2	Lim Sw
30	105	2	Lim Sw
31	105	2	Lim Sw
32	105	2	Lim Sw
33	105	2	Lamp

The "Approximate I/O Cost (per point)" value in the "Material Unit Cost" section below is £18.00 for 1771 (default). Change this value to £12.00 for 1746 (SLC) I/O.

Flex I/O Model

PLC processor is in central panel and Flex I/O is located in J.B.s. There are two runs of conduit from the central panel, one for power and one for RIO cable. The toolkit assigns J.B.s and Flex I/O based on distance from head end and max device cable length. Increase the max cable length to reduce number of Flex I/O blocks.

DeviceNet Model

DeviceNet scanner is in central panel. DeviceNet trunkline is run open, not in conduit. Each device connects via single or 8-point taps with a 10-ft. maximum dropline. You enter the number of 8-point taps in the "Measurements and Quantities" section below.

Adjusting Defaults

You may modify any default cost or configuration assumption that is displayed in a green cell, such as labour rate, spare capacity, etc.

34	105	2	Lamp
35	105	2	Lamp
36	105	2	Lamp
37	115	2	Valve
38	115	3	Valve
39	115	3	Valve
40	115	3	Valve
41	115	3	Valve
42	115	3	Valve
43	115	3	Valve
44	115	3	Valve
45	115	3	Valve
46	115	3	Valve
47	115	3	Valve
48	115	3	Valve
49	115	3	Valve
50	115	3	Valve
51	115	3	Valve
52	122	3	Photo
53	122	3	Photo
54	122	3	Photo
55	122	3	Photo
56	122	3	Photo
57	122	2	Sel Sw
58	122	2	Sel Sw
59	122	2	Sel Sw
60	122	2	P.Button
61	122	2	Lim Sw
62	122	2	Lim Sw
63	122	2	Lim Sw

	1771/1746 DIRECT	FLEX I/O	DEVICENET
Total Installed Cost (rounded to nearest £100.00)	£2,800	£1,700	£2,800

PREFERENCES ENTRY

	1771/1746 DIRECT	FLEX I/O	DEVICENET
SPARE CAPACITY			
Required Spare Capacity (Wires, I/O, T.B.)	20%	20%	20%
MEASUREMENTS & QUANTITIES			
Total Conduit or Trunkline Length (feet)	111	0	111
Maximum Device Cable Length (feet)	30	30	20
Qty. of Junction Boxes or Tap Locations	1	1	14
Total Number of Devices	63	63	63
Number of 8-point DeviceNet Taps			7
Input Points (per I/O card)	16	16	128
Are all wires terminated in each junction box?	y		
LABOUR UNIT COSTS			
Labour Time (minutes) per Connection:	1.2	1.2	1
Labour Rate (pounds per hour):	£23	£23	£23
Cost per ft. to install Conduit or Trunkline:	£1.20	£1.20	£0.90
Cost to Install Junction Box or Tap	£13	£13	£7
Estimated Rework Labour Percentage	10%	4%	2%
MATERIAL UNIT COSTS			
Cost per Junction Box	£16	£32	
Incremental Cost of DeviceNet Device	£0	£0	£21
Cost per Terminal Block	£1		
Cost per ft. of Wire (14 AWG)	£0.10		
Cost of 3/4 Inch Conduit, per foot	£1.00		
Cost of 1 Inch Conduit, per foot	£1.00		
Cost of 1-1/4 Inch Conduit, per foot	£1.00		
Cost of 1-1/2 Inch Conduit, per foot	£1.10		
Cost of 2 Inch Conduit, per foot	£1.24		
Approximate I/O Cost (per point)	£12	£12	
Cost per DeviceNet Scanner			£343
Cost of RIO or DeviceNet Cable per foot		£0.46	£0.37
Cost per DeviceNet Connector, 1 tap			£29.00
Cost per DeviceNet Connector, 8 tap			£93.00

	1771/1746 DIRECT	FLEX I/O	DEVICENET
INTERMEDIATE CALCULATIONS			
Feet of Power & Control Wire:	9403	221	
Feet of RIO or DeviceNet Cable Length:		112	113
Number ofTerminal Blocks:	102		
Number of DeviceNet Connectors, 1 tap:			7
Number of DeviceNet Connectors, 8 tap:			7
Number of I/O Connections:	114	118	5
Number of Flex I/O Adapters:		1	
Number of I/O or DeviceNet Scanner Cards:	7	7	1
LABOUR CALCULATIONS			
Wiring Labor Time (minutes):	381	282	96
Total Wiring Labour Cost:	£146	£108	£37
Labour Cost to Install Conduit:	£133	£0	£0
Labour Cost to Install DeviceNet Trunkline:			£100
Labour Cost to Install Junction Boxes:	£13	£13	£91
Total Labor Cost Before Rework:	£292	£121	£227
Cost to Rework Wiring Errors:	£29	£5	£5
Total Labor Cost	£321	£126	£232
MATERIAL CALCULATIONS			
Total Incremental Device Cost:	£0	£0	£1,323
Total Cost of Junction Boxes:	£16	£32	
Total DeviceNet Connector Cost:			£854
Total RIO or DeviceNet Cable Cost:		£0	£41
Total Terminal Block Cost:	£102		
Total Wire Cost:	£940	£22	
Estimated I/O Hardware Cost:	£1,344	£1,344	£343
Total Conduit Cost:	£122	£221	
Total Material Cost	£2,524	£1,619	£2,561

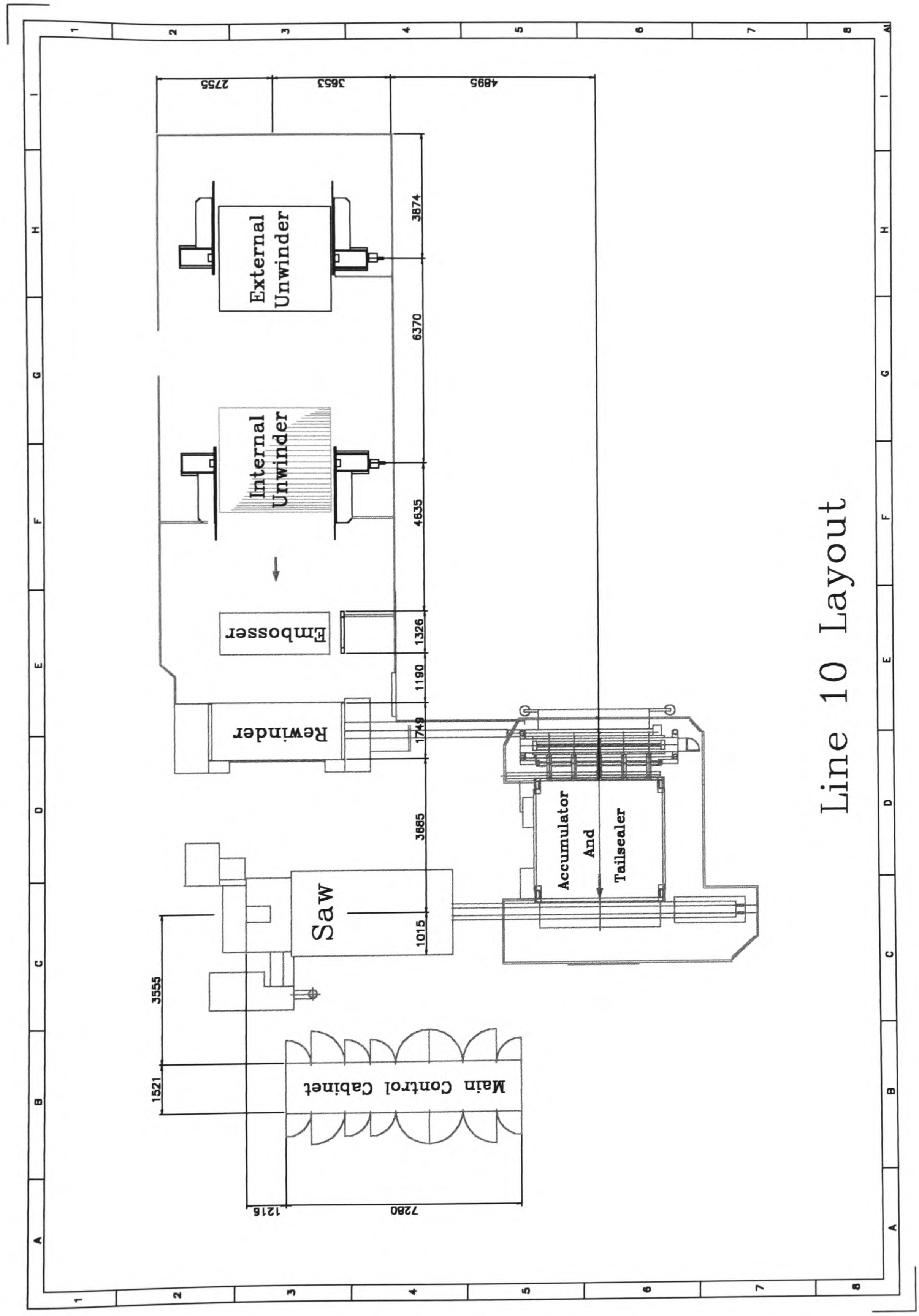
APPENDIX C

FIELD TRIAL NOTES

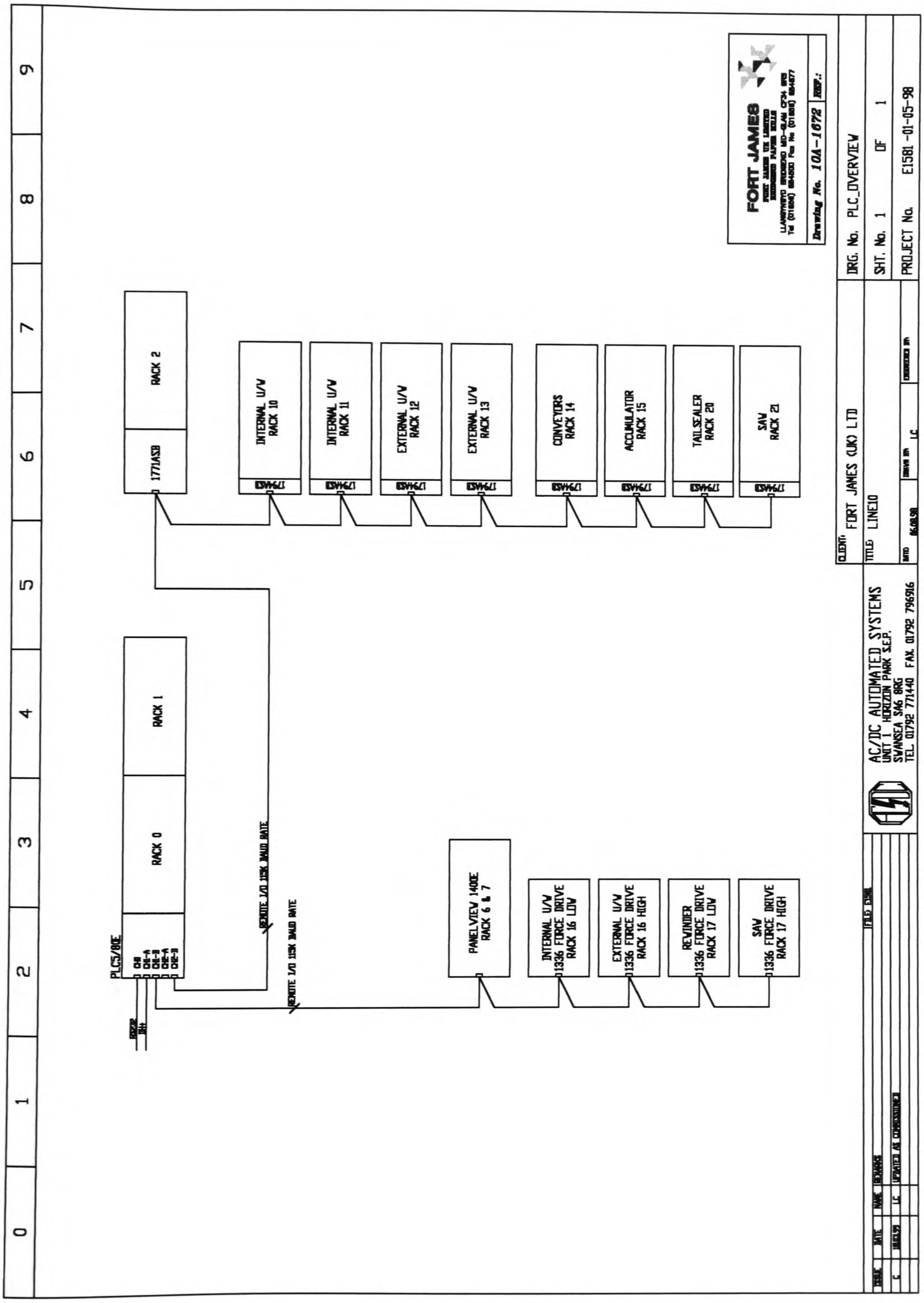
C.1 Line 10 Rewinder Layout Drawings

C.2 Remote I/O Overview of Line 10

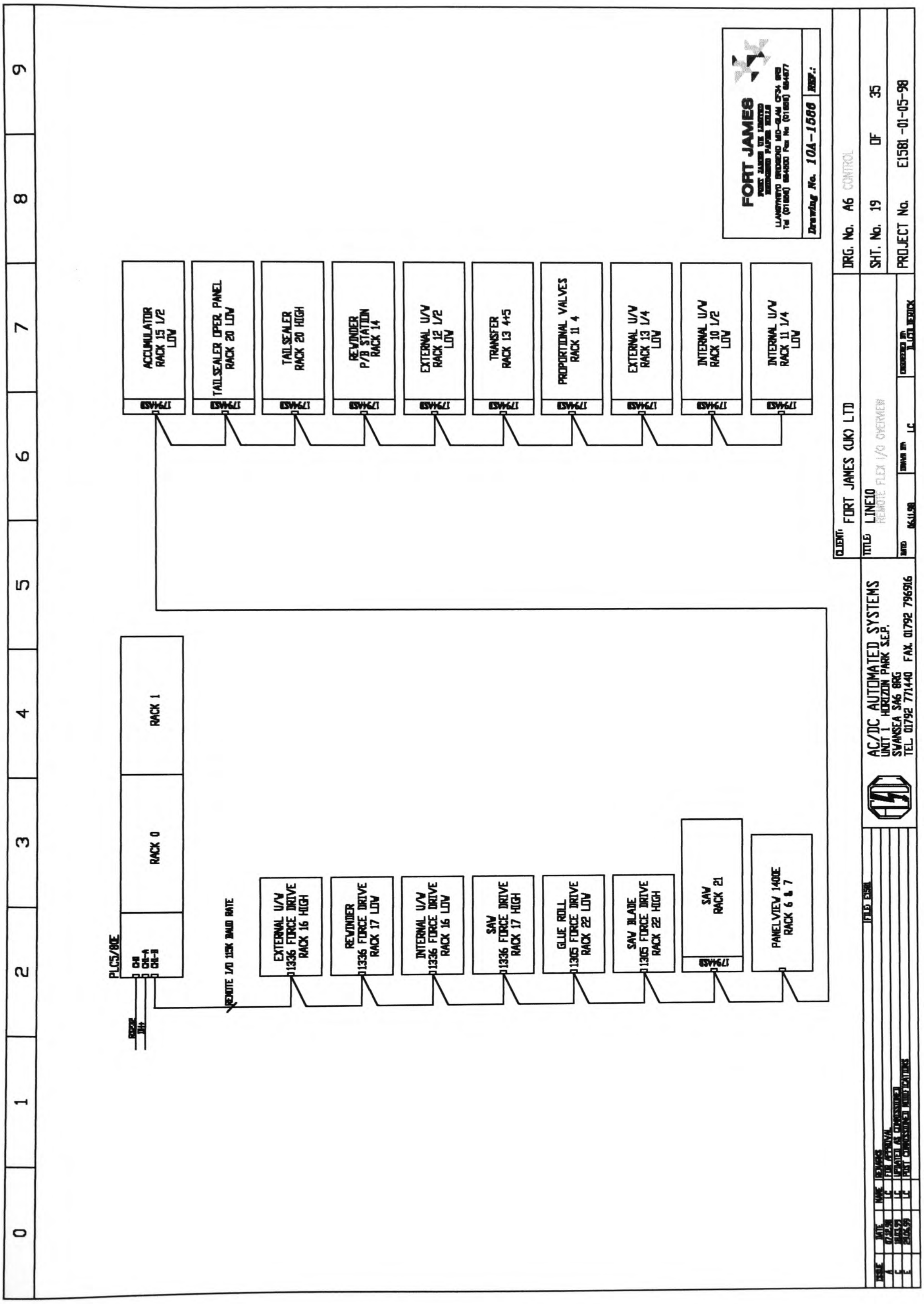
C.1 LINE 10 REWINDER LAYOUT DRAWING


Line 10 Layout
External Unwinder
Internal Unwinder
Embosser
Rewinder
Accumulator And Tailsealer
Saw
Main Control Cabinet
2755
3653
4895
3874
6370
4635
1326
1190
1749
3685
1015
3555
1521
1216
7280

C.2 LINE 10 REMOTE I/O OVERVIEW



PLC5/80E
CH0
CH1-A
CH1-B
CH2-A
CH2-B
RS232
DH+
RACK 0
RACK 1
1771ASB
RACK 2
REMOTE I/O 115K BAUD RATE
REMOTE I/O 115K BAUD RATE
PANELVIEW 1400E RACK 6 & 7
INTERNAL U/V 1336 FORCE DRIVE RACK 16 LOW
EXTERNAL U/V 1336 FORCE DRIVE RACK 16 HIGH
REWINDER 1336 FORCE DRIVE RACK 17 LOW
SAW 1336 FORCE DRIVE RACK 17 HIGH
1794ASB
INTERNAL U/V RACK 10
INTERNAL U/V RACK 11
EXTERNAL U/V RACK 12
EXTERNAL U/V RACK 13
CONVEYORS RACK 14
ACCUMULATOR RACK 15
TAILSEALER RACK 20
SAW RACK 21
FORT JAMES
Drawing No. 10A-1672
REF.:
ISSUE DATE NAME REMARKS
C LC UPDATED AS COMMISSIONED
AC/DC AUTOMATED SYSTEMS
UNIT 1 HORIZON PARK S.E.P.
SWANSEA SA6 8RG
TEL. 01792 771440 FAX. 01792 796916
CLIENT: FORT JAMES (UK) LTD
TITLE: LINE10
DRAWN BY LC
DRG. No. PLC_OVERVIEW
SHT. No. 1 OF 1
PROJECT No. E1581-01-05-98


PLC5/80E
RACK 0
RACK 1
REMOTE I/O 115K BAUD RATE
EXTERNAL U/W 1336 FORCE DRIVE RACK 16 HIGH
REWINDER 1336 FORCE DRIVE RACK 17 LOW
INTERNAL U/W 1336 FORCE DRIVE RACK 16 LOW
SAW 1336 FORCE DRIVE RACK 17 HIGH
GLUE ROLL 1305 FORCE DRIVE RACK 22 LOW
SAW BLADE 1305 FORCE DRIVE RACK 22 HIGH
SAW RACK 21
PANELVIEW 1400E RACK 6 & 7
ACCUMULATOR RACK 15 1/2 LOW
TAILSEALER OPER. PANEL RACK 20 LOW
TAILSEALER RACK 20 HIGH
REWINDER P/B STATION RACK 14
EXTERNAL U/W RACK 12 1/2 LOW
TRANSFER RACK 13 4+5
PROPORTIONAL VALVES RACK 11 4
EXTERNAL U/W RACK 13 1/4 LOW
INTERNAL U/W RACK 10 1/2 LOW
INTERNAL U/W RACK 11 1/4 LOW
1794ASB
AC/DC AUTOMATED SYSTEMS
UNIT 1 HORIZON PARK S.E.P.
SWANSEA SA6 8RG
TEL. 01792 771440 FAX. 01792 796916
CLIENT: FORT JAMES (UK) LTD
TITLE: LINE10
REMOTE FLEX I/O OVERVIEW
DRG. No. A6 CONTROL
SHT. No. 19 OF 35
PROJECT No. E1581-01-05-98
FORT JAMES
Drawing No. 10A-1586